U.S. Army Research Institute
for the Behavioral and Social Sciences

Research Report 1518

Increasing the Combat Effectiveness of the Bradley Fighting Vehicle: New and Modified Thermal Training Procedures and Products

David F. Champion, Robert L. Rollier, Donald P. Frederick,
Paul R. Roberson, and Stephen D. Knapp
Litton Computer Services Division, Litton Systems, Inc.

August 1988

U.S. ARMY RESEARCH INSTITUTE FOR THE BEHAVIORAL AND SOCIAL SCIENCES

A Field Operating Agency Under the Jurisdiction of the Deputy Chief of Staff for Personnel

EDGAR M. JOHNSON
Technical Director

JON W. BLADES
COL, IN
Commanding

Research accomplished under contract
for the Department of the Army

Litton Computer Services Division
Litton Systems, Inc.

Technical review by

Ronald E. Kraemer
Robert J. Pleban

A-1

NOTICES

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS --
2a. SECURITY CLASSIFICATION AUTHORITY -- 2b. DECLASSIFICATION / DOWNGRADING SCHEDULE --	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
4. PERFORMING ORGANIZATION REPORT NUMBER(S) --	5. MONITORING ORGANIZATION REPORT NUMBER(S) ARI Research Report 1518
6a. NAME OF PERFORMING ORGANIZATION Litton Computer Services Div., Litton Systems, Inc. 6b. OFFICE SYMBOL (If applicable) --	7a. NAME OF MONITORING ORGANIZATION U.S. Army Research Institute Field Unit at Fort Benning, GA
6c. ADDRESS (City, State, and ZIP Code) P.O. Box 7113 Mountain View, CA 94039-7113	7b. ADDRESS (City, State, and ZIP Code) P.O. Box 2086 Fort Benning, GA 31905
8a. NAME OF FUNDING/SPONSORING ORGANIZATION U.S. Army Research Institute for the Behavioral and Social Sciences 8b. OFFICE SYMBOL (If applicable) PERI-I	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER MDA903-85-C-0400
8c. ADDRESS (City, State, and ZIP Code) 5001 Eisenhower Ave. Alexandria, VA 22333-5600	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 63744A; PROJECT NO. 795; TASK NO. 342; WORK UNIT ACCESSION NO. C1

11. TITLE (Include Security Classification) Increasing the Combat Effectiveness of the Bradley Fighting Vehicle: New and Modified Thermal Training Procedures and Products

12. PERSONAL AUTHOR(S) Champion, David F., Rollier, Robert L., Frederick, Donald P., Roberson, Paul R., and Knapp, Stephen D. (Litton Computer Services Division, Litton Systems, Inc.)

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 85/09 TO 87/09	1988, August	60

16. SUPPLEMENTARY NOTATION
Contracting Officer's Representative: Seward Smith

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Scanning techniques, Thermal training, Bradley Fighting Vehicle (BFV), integrated sight unit, Thermal camouflage, Thermal sight, Thermal detection

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report describes exploratory research on the effects of camouflage, cover, and concealment on detection and classification of thermal targets. It is extremely difficult to conceal the thermal signature of a vehicle in a surveillance position. The use of cut foliage and defilade positioning, however, were found to make classification and detection equally difficult. Researchers developed and field tested a set of thermal training guidelines that address sight control manipulation, scanning, target acquisition, and range estimation. These procedures, along with a slide presentation, form a thermal training package that is under review. Observation of gunners showed that some of the thermal sight controls rotated so freely that it was easy to inadvertently displace them. Experimentation showed that placing vinyl grommets between these knobs and the panel provided sufficient friction and solved this problem.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Seward Smith	22b. TELEPHONE (Include Area Code) (404) 835-5589 22c. OFFICE SYMBOL PERI-IJ

DD Form 1473, JUN 86 Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

Research Report 1518

Increasing the Combat Effectiveness of the Bradley Fighting Vehicle: New and Modified Thermal Training Procedures and Products

David F. Champion, Robert L. Rollier, Donald P. Frederick,
Paul R. Roberson, and Stephen D. Knapp
Litton Computer Services Division, Litton Systems, Inc.

Field Unit at Fort Benning, Georgia
Seward Smith, Chief

Training Research Laboratory
Jack H. Hiller, Director

U.S. Army Research Institute for the Behavioral and Social Sciences
5001 Eisenhower Avenue, Alexandria, Virginia 22333-5600

Office, Deputy Chief of Staff for Personnel
Department of the Army

August 1988

Army Project Number
2Q263744A795

Training and Simulation

FOREWORD

The Army Research Institute for the Behavioral and Social Sciences (ARI) has contributed to an ongoing program to define emerging problems and address critical issues affecting the Bradley Fighting Vehicle (BFV). Consistent with that program, this report describes equipment and training modifications and changes intended to improve the combat capability of the BFV. Further, because the vehicle incorporates advanced weapons systems and sights to be used under limited visibility, special emphasis was given to research that focused on operations under these kinds of conditions.

ARI's Fort Benning Field Unit, a division of the Training Research Laboratory, monitored this research. ARI's mission is to conduct research of training and training technology using infantry combat systems and problems as mediums. The research task which supports this mission is 3.4.2., "Advanced Methods and Systems for Fighting Vehicle Training," organized under the "Train the Force" program area. Sponsorship for this research is provided by a Memorandum of Understanding (effective 31 May 1983) between the U.S. Army Infantry School (USAIS), Training and Doctrine Command, Training Technology Agency, and ARI, which established how joint efforts to improve BFV tactical doctrine, unit, and gunnery training would proceed.

Officers and instructors from throughout the Bradley Instructor Detachment, 1st Battalion, 29th Infantry Regiment were briefed on the research projects reported here and much of the material has been incorporated into the Bradley programs of instruction.

EDGAR M. JOHNSON
Technical Director

INCREASING THE COMBAT EFFECTIVENESS OF THE BRADLEY FIGHTING VEHICLE: NEW AND MODIFIED THERMAL TRAINING PROCEDURES AND PRODUCTS

EXECUTIVE SUMMARY

Requirement:

Litton Computer Services (LCS) operated under contract to and with guidance from the Army Research Institute (ARI) located at Fort Benning, Georgia. LCS investigated the operational parameters of the thermal sight and developed procedures and training materials that would enhance the performance of Bradley Fighting Vehicle (BFV) gunners using the thermal sight.

Procedure:

Research focused on the effects of target camouflage, cover, and concealment on thermal sight usage. The research was divided into two phases, an exploratory phase and an experimental phase. Data collected in the exploratory phase were used to modify training materials and operational procedures. The materials and procedures were then tested in the experimental phase.

Findings:

The results of this 2-year research program include:

- o A thermal training package that comprises a slide presentation and a handbook on thermal sight usage for gunners. The handbook contains procedures for obtaining a thermal image, scanning, classifying thermal detections, and range estimation.
- o A data base on the effects of camouflage, cover, and concealment on thermal detection and classification of targets.
- o A simple technique for taking color slides through the thermal sight.
- o A method of modifying selected thermal sight controls to avoid inadvertent mis-setting.
- o Exploratory work on a method of measuring image quality on thermal sights.

Utilization of Findings:

The thermal training materials will reduce training time, facilitate on-the-job training, and improve the efficiency of thermal sight use by BFV gunners. Knowledge of the effects of camouflage, cover, and concealment will provide a basis for developing guidelines for thermal camouflage of friendly vehicles. Modifications to thermal controls will increase the efficiency with which a gunner can engage the enemy. Development of a procedure for taking color slides through the thermal sight will facilitate the creation of new training aids. The exploratory work on measuring the quality of image of the thermal sight may, if pursued, facilitate prediction of the need for sight maintenance, and thereby enhance unit readiness.

INCREASING THE COMBAT EFFECTIVENESS OF THE BRADLEY FIGHTING VEHICLE: NEW AND MODIFIED THERMAL TRAINING PROCEDURES AND PRODUCTS

CONTENTS

	Page
INTRODUCTION	1
Background	2
CAMOUFLAGE, COVER, AND CONCEALMENT: EXPLORATORY PHASE	4
Method	4
Findings	5
Discussion	7
Summary and Conclusion	8
CAMOUFLAGE, COVER, AND CONCEALMENT: EXPERIMENTAL PHASE	9
Method	10
Results	16
Discussion	28
THERMAL TRAINING PACKAGE	32
The Handbook	32
The Slide Presentation	33
Test of Initial Thermal Image Procedure	33
Test of Procedure for Marking the Thermal Controls	35
OTHER RESEARCH	35
Through-the-Sight Photography	35
Thermal Sight Classification Techniques	38
Modifications to Thermal Sight Controls	41
Use of Special Camouflage Materials	42
SUMMARY	42
RECOMMENDATIONS	43
REFERENCES	45
APPENDIX A. Table 7. Targets used in scenario A	47
Table 8. Targets used in scenario B	48
APPENDIX B. Table 9. Temperature (F) and humidity (percent) recorded on the four days of experimentation	49

Page

APPENDIX C. Factors affecting the experimental design 51

APPENDIX D. Table 10. Results of multiple regression analysis: Detections on polarity usage and scanning pattern for the 35 subjects in scenario A 53

APPENDIX E. Table 11. Results of multiple regression analysis: Scanning times on polarity usage and scanning pattern for the 35 subjects in scenario A 55

LIST OF TABLES

Table 1. Means and associated standard deviations and ranges found for the times taken to obtain an initial focus for each group in each scenario 17

2. Number of gunners in each group using the specified scanning techniques 19

3. Means of the ratings for polarity usage and scanning techniques found for the control and treatment groups in scenario A 20

4. Mean number of targets detected and mean scanning times found for each group in each scenario, and the results of the t-tests between the groups 22

5. Mean point scores found for the quality of range cards 24

6. Mean percentage errors of estimate by group across scenarios 26

LIST OF FIGURES

Figure 1. Two-pronged mounting bracket 36

INCREASI... THE COMBAT EFFECTIVENESS OF THE BRADLEY FIGHTING VEHICLE: NEW AND MODIFIED THERMAL TRAINING PROCEDURES AND PRODUCTS

INTRODUCTION

This report describes developments in thermal research conducted by Litton Computer Services (LCS) under the guidance of the Army Research Institute (ARI) at Fort Benning, Georgia, between September 1985 and September 1987. The primary concern was with the way gunners use the thermal mode of the integrated sight unit (ISU) of the Bradley Fighting Vehicle (BFV). The thrust of the research was toward identifying techniques and creating guidelines and procedures that enable BFV gunners to make more effective use of the thermal sight.

The research is part of an ongoing process that has its origins in earlier work and leaves questions that must be answered by future experimentation. To establish the context, earlier studies will be summarized before the current work is described. However, briefly stated, thermal research conducted in this reporting period has concentrated on the following areas:

1) Investigating the effects of camouflage, cover, and concealment on the appearance of targets that gunners see through the thermal sight.

2) Identifying the thermal cues that enable gunners to classify camouflaged targets.

3) Testing sector scanning techniques and exploring range estimation techniques for camouflaged targets.

4) Preparing and testing procedures that enable gunners to obtain a fast, effective, initial thermal image.

5) Testing and modifying previous thermal training guidelines in the light of new information.

6) Designing and testing modifications to the thermal sight controls to facilitate control manipulation.

7) Developing techniques for taking color photographs through the thermal sight that show targets as they actually appear.

8) Testing the efficacy of thermal reflective materials for camouflage.

Background

Research into the capabilities of the thermal sight began in early 1985. At that time, the BFV was newly fielded and few guidelines on sight usage had been formulated. Conflicting reports about the utility of the sight existed, and assertions were made that ranged from one suggesting it was of no value beyond 600 meters to claims by the manufacturer that it was capable of detecting targets at several thousand meters. Subsequent investigation showed that, although the thermal sight controls are ill-designed from an ergonomic viewpoint, the sight itself has great value for night surveillance and is certainly capable of detecting targets at ranges in excess of the maximum range of the TOW missile.

The major problem identified was the gunners' lack of clear guidance on thermal sight usage. This was inevitable because, at that time, there was insufficient information about the sight for accurate and effective teaching guidelines to have been formulated. Gunners were told that the thermal controls should be adjusted like those on a television set; that is, by adjusting the focus, contrast, and brightness knobs until the image looked good. No guidance was provided on what constituted good, nor were gunners instructed to readjust the controls to compensate for changes in background, target types, viewing distances, or climatic factors. No photographs or visual aids were available to teach BFV gunners about thermal cues or the thermal appearance of targets. On the tactical level, no techniques had been defined for conducting sector searches and range estimation while operating in the thermal mode. In short, a clear need for a thermal training program existed. It was to meet this need that thermal research was undertaken.

Initial experimentation began in May 1985. Its purposes were to assess the capabilities of the ISU, to define optimum manipulation techniques for obtaining a clear thermal image rapidly, and to explore ways of increasing the probability of detecting targets. The intent was to build a data base from which teaching guidelines could be defined. Information was gathered on the effects of changes in the settings for brightness, contrast, focus, polarity, and magnification on the gunner's sight picture; on the reliability and consistency of the thermal images over time, across vehicles, and as a result of vehicular movement; and on the effects of changes in the weather. Individual preferences in type of sight picture were recorded, and exploratory work on through-the-sight photography techniques was undertaken.

From the information obtained, a set of guidelines was developed for using the thermal sight. These guidelines were tested in August 1985. A class on the use of the thermal sight was given to a group of soldiers who were about to join BFV units, and the performance of these troops was compared with that of a group of established BFV gunners. The results showed that those who had received the class did as well as, and in some respects better than, the experienced gunners (Rollier, Salter et al., 1988).

These results demonstrated that the procedures and techniques deduced from earlier analyses were more effective than those that were then being generally taught to BFV gunners. The guidelines were documented in three booklets. Each booklet covered a different aspect of thermal sight usage: sight control manipulation, scanning techniques, and range estimation. These booklets were distributed to obtain feedback on their utility as instructional documents (BIFV Scanning Techniques, 1986; BIFV Thermal Operations, 1986; BIFV Range Card, 1986).

Concurrently, work on developing techniques for through-the-sight photography was begun. This involved both color slides and black and white video. The work was undertaken with the goal of creating visual aids for instructional purposes that would reproduce the thermal image seen by the gunner. Although the resulting slides and videos were not of the quality required for teaching purposes, they were sufficiently encouraging to warrant continued research.

Research and experimentation up to this point (September 1985) had dealt with targets that were in the open. The next phase examined the impact of camouflage, cover, and concealment on the effectiveness of the thermal sight, on the way it should be used, and explored the training implications. The effectiveness of the thermal sight for detecting camouflaged targets had not been previously investigated. A search of the existing literature and discussion with subject matter experts (SMEs) showed that no guidelines or procedures had been established. Clearly, any hostile force will take full advantage of camouflage, cover, and concealment to hide its forces and will utilize movement by night to hide its intentions. Therefore, the gathering of accurate data on what can be discerned through the thermal sight in such circumstances is of importance.

CAMOUFLAGE, COVER, AND CONCEALMENT: EXPLORATORY PHASE

Objective

The first phase of research was exploratory and was conducted with a view to collecting basic data. The objective was to build an information base about the effects of camouflage, cover, and concealment on the appearance of targets seen through the thermal sight, and on the implications such effects might have for operator performance. To gather the data, a field experiment was conducted.

Method

Subjects

Six SMEs who were experienced in the use of the thermal sight were used as subjects. The judgments and observations of these SMEs constituted the data that were collected. Three of the SMEs were research staff with military backgrounds, and the other three were military personnel currently serving on BFVs.

Materials

Four targets and six observation vehicles were used. The observation vehicles were all BFVs; the targets were an M1 tank, an M2 BFV, an M113 personnel carrier, and a 2.5-ton truck.

Procedure

The experiment was conducted over five nights during July 1986 at Caramouche Range, Fort Benning, Georgia. Temperatures varied between 82 and 78 degrees Fahrenheit; a light rain fell during the first two hours of observation on the second and third evenings.

Each target was observed while positioned at each of four different target location points. Each target location point was at a different range; these were 1180, 2120, 3340, and 3850 meters. Each location allowed sufficient room for targets to maneuver and was suitable for using different forms of camouflage, cover, and concealment. Targets were rotated through each of the four locations. At each location, they were observed in four different attitudes (right flank, left flank, front, and rear of vehicle toward the observers), and with the engine idling and with it revving. In each of these positions, four types of camouflage, cover, and concealment were employed. These were live vegetation (targets in tree lines or behind standing vegetation), cut vegetation, camouflage nets, and a special thermal reflective material. Both the camouflage nets and the thermal reflective material were tested draped over the targets and as screens separate from the targets but placed between them and the observers. In addition, using natural folds in the ground, targets were observed in both partial defilade (only upper hull exposed) and complete defilade positions (vehicle totally concealed from direct line of sight viewing).

For each new arrangement of targets, each observer recorded his ability to detect, classify, and identify the targets. The definitions of these terms are as follows: detection is the discovery of a thermal source or temperature disparity in the field of view that warrants further investigation; classification is the gross differentiation of targets according to class (e.g., tank, truck, wheeled vs. tracked, personnel); and identification is the determination, within a class, of the specific identity of a target (e.g., Abrams tank, M60 tank).

In this experiment the observers knew what the targets were and where they were located. The focus was not in whether the observers could detect the targets, but in ascertaining characteristics of the four targets that would enable others to detect, classify, and identify them. The observers recorded what they could see using first white hot and then black hot polarity, in both low and high magnification. This was supplemented by sketches of the appearance of targets showing particular identifying features. Subsequent comparison of the sketches, supplemented by the observers' records, written notes, and verbal comments, enabled common and/or distinctive features to be identified.

A through-the-sight photographic record was kept of the thermal appearance of each target in each attitude and at each location. This proved a valuable aid in subsequent discussions of the effectiveness of different types of camouflage. The quality of color slides produced on this occasion were superior to any produced previously, and were adequate for teaching purposes. Research into black and white through-the-sight video techniques was discontinued at this point, initially because of equipment failure, but subsequently because the equipment was required by the Department of the Army for other purposes.

Findings

Detectability of Thermal Signatures under Camouflage

Based on the sample of observations, the following conclusions were reached about the effects of the different forms of camouflage.

Live vegetation. Live vegetation is effective in reducing the detectability of thermal signatures. The effectiveness is proportional to the depth of the target within the tree line and/or the thickness of the vegetation between the target and the thermal sight. Any increase in the amount of overlap of even small or thin vegetation increases thermal shielding.

Cut vegetation. This mode of camouflage reduces the thermal signature of targets. The amount of cut vegetation required to hide the thermal image of a target is greater than the amount required to prevent visual detection using the daylight sight. The effectiveness of cut vegetation as thermal camouflage is not noticeably degraded by decay; even when color change makes the decaying vegetation readily distinguishable through the daylight sight it still provides thermal screening.

Camouflage nets. The camouflage nets that are currently issued to units do little to break up the thermal outline of targets. A net alone did not prevent detection or seriously impede classification at the 1180- or the 2120-meter target location points.

Total defilade. Placing a vehicle in a total defilade position completely blocks the thermal signature of the vehicle, leaving no residual halo or radiance above or about the target. However, if there is overhanging foliage near the point where the target is concealed, this can become heated by the target's exhaust emissions and will then betray the target's location.

Partial defilade. Partial or hull defilade eliminates two principal heat sources: the engine and the wheels or tracks. By concealing these, cues an enemy can use to help classify a detection are denied.

Thermal barrier material. This technique shows promise for use in the field, although questions about the fragility of the material were raised. When placed on or over a target, so that it touched hot areas, it was found to be easily damaged, resulting in heat leaks. However, when a screen of the same material was erected between a target and the observers, the thermal signature of the target was completely obscured. The material showed sufficient potential to warrant continued experimentation.

Thermal Detectability of Target Vehicles

M1 tank. Because of its turbine engine, the M1 was found to have a very strong thermal signature. The exhaust emissions were found to be so hot that even with the vehicle in complete defilade, the heat bloom on nearby trees and foliage was easily detected. Indeed, when viewed through the thermal sight, trees to the rear of the vehicle looked on occasions as if they had been illuminated. Although the M1 provides a large, very hot and therefore detectable image, its low irregular shape makes it difficult for the observer to classify or identify.

M2 BFV. When viewed through the thermal sight, the BFV was found to have no particular characteristic that made it easily identifiable.

M113 personnel carrier. This vehicle has three distinctive features when viewed through a thermal sight: its box-like shape, the sharp change in angle at the front of the vehicle, and the trim vane. The angle at the front stands out because the engine is mounted in the front, and therefore the hull front radiates more heat. The trim vane shows up in the thermal sight as a distinct rectangle. This is because it is made of wood and therefore always tends to be at a different temperature from that of the hull. These features make the M113 relatively easy to identify at ranges out to 2000 meters.

2.5-ton truck. The intensity of this vehicle's heat emissions rivals that of the M1. The engine compartment and the vertical exhaust provide a very hot and distinctive target.

General Findings

In general, two factors made detection easier. These were movement and intensity of heat emission from the target.

Movement. The probability of detecting a target was markedly increased when the vehicle was moving. Even when heat emissions were low or well shielded, the movement itself attracted attention.

Intensity of heat emission. Revving the engines of stationary vehicles made detection easier. Not only did the engine areas become hotter, but the exhaust gases formed a heat plume above the vehicle and heated the surrounding foliage. This happened for all targets. The attitudes of the targets to the observer were also important; when the exhaust side of the vehicle was toward the observers, the vehicle was more easily detected and more difficult to camouflage effectively. When the opposite side of the vehicle was toward the observers, the probability of detection was reduced noticeably.

Use of thermal controls for classification. Once a target had been detected, it was examined in high magnification. SMEs found classification was easier when the polarity was changed frequently. Black hot brought out the shape or silhouette of a target more clearly; switching to white hot enabled the placing of hot areas such as engine or exhaust within this hull shape.

Discussion

The placing of almost any material between a target and an observer will reduce the thermal signature of the target. However, reduction of thermal signature does not preclude detection. When a vehicle is in a forward position, it is difficult using camouflage or concealment to reduce the overall thermal difference between a target and its background, and to maintain that low differential at a point where detection is unlikely. Indeed, changes in the weather, the need to run engines to charge batteries with the attendant chance of heat bloom on surrounding foliage, and essential movement of personnel make it almost impossible. Freedom from thermal detection can be certain only where vehicles are placed in cover out of direct line of sight of the enemy. However, detection implies only that a heat source or thermal anomaly is noticed by a gunner and is deemed worthy of further examination. All detections are not of military interest. Wildlife, exposed areas of rock that have been heated by the sun, and other natural features can appear as relatively intense heat sources. Therefore, where the thermal signature of a vehicle cannot be totally screened, camouflage and concealment should be used with the intent of diminishing the amount of heat radiated from the vehicle toward enemy detectors and disrupting its thermal appearance.

For vehicles in forward positions, the intent of camouflage and concealment should be to render a vehicle difficult to classify. This is advantageous for two reasons. First, if the enemy cannot determine the nature of a heat source, they cannot be certain it is a military target, and therefore, may be unwilling to reveal their own positions by firing. Second, even if the enemy deduce the presence of a military unit and decide to fire on it, their inability to classify may result in the selection of an inappropriate weapon system. More obviously, in a battlefield environment where extraneous heat sources such as destroyed equipment exist or where artillery fire has created hot spots, a detection that cannot be classified may pass unnoticed by the enemy.

Summary and Conclusion

The experiment showed that the following factors would make classification more difficult:

- Positioning vehicles in partial defilade with the exhaust systems facing away from the enemy materially reduces the amount of heat radiated toward the enemy, and hides classification cues such as tracks or wheels.

- Placing live or cut vegetation in front of the exposed areas of the vehicle disrupts the outline and reduces the size of the thermal signature.

- Positioning the vehicle so that exhaust gases do not play directly onto trees or bushes helps ensure that the vehicular nature of the heat source is not betrayed by heat bloom.

- Camouflaging salient features of vehicles makes accurate classification much more difficult. For example, camouflage should be used to break up the rectangular shape of the trim vane on the M113.

The exploratory work showed that the thermal sight is an extraordinarily powerful tool for detecting camouflaged vehicles and, by extension, enemy positions; indeed, observation of the targets by SMEs during daylight (prior to experimentation) suggested that it is as useful for this purpose in daytime as it is at night. However, while the sight facilitates the detection of a heat source, the interpretation of image (classifying the detection) is not easy. Further research is needed, using camouflaged threat vehicles, to determine the distinguishing features by which these can be easily identified.

CAMOUFLAGE, COVER, AND CONCEALMENT: EXPERIMENTAL PHASE

This phase comprised a formal experiment in which subjects were required to detect camouflaged targets. Concurrent with this work, research continued into through-the-sight photography, into ways of improving the thermal sight controls, and into methods of classifying the quality of sight images.

Objective

The primary objective of the experiment was to test the efficacy of the thermal training materials being developed by the research team. These training materials had been modified in light of what had been learned about the detection and classification of camouflaged targets in the exploratory work, and were supplemented by color slides of thermal images. Testing had two aspects. First, it was to determine whether the sight control manipulation, scanning, target classification, and range estimation techniques that had been deduced from the exploratory experiment work were more effective than techniques currently in use. Second, it was to see whether classroom teaching was an effective method of communicating these techniques, especially when the target audience was experienced gunners who had preconceived ideas of the best way to use the thermal sight.

Two sets of experimental hypotheses were generated. The first set was concerned with the efficacy of classroom instruction as a method of modifying the techniques used by trained gunners. Specifically, it was predicted that when the techniques used by gunners who were familiar with the new training materials (treatment group) were compared with the techniques used by gunners who relied on their previous training (control group), more subjects in the treatment group would:

1) Scan with polarity set to white hot,

2) Scan systematically in the horizontal plane,

3) Produce a better quality range card,

4) Make greater use of the range card in the turret,

5) Achieve an initial focus quickly.

The second set of hypotheses was concerned with the efficacy of the recommended techniques themselves. It was recognized that not all the subjects in the treatment group would necessarily follow the recommended techniques and that some of those in the control group might coincidentally use them. Therefore, a simple comparison of the performance of the control group with that of the treatment group was not seen to be an appropriate method of testing the relative efficacy of techniques. This was borne in mind when formulating the two hypotheses, which were:

1) Those who scanned with polarity set to white hot and who scanned systematically in the horizontal plane would both detect more targets and take less time to complete scanning than those who used other techniques.

2) Those who made better range cards and who used range cards more frequently in the turret to help estimate range would estimate range more accurately than those who used other methods.

It was not possible to define any one technique or combination of techniques that could be easily measured and could also be expected to correlate with improved classification of targets. Therefore, it was simply predicted that the treatment group would on average achieve a higher number of correct classifications than would the control group.

Method

Subjects

Although the experimental design called for 36 subjects, for reasons beyond the experimenters' control, only 35 were available for the experiment. The subjects were all currently assigned to a Bradley squad or platoon, and all were military occupational specialty (MOS) trained gunners. The rank of the subjects varied from E-4 (Gunner) to E-7 (Platoon Sergeant/Acting Platoon Leader). Every effort was made to balance the two groups in terms of rank, time in service, time in grade, education, and physical characteristics such as eyesight and left-right-handedness. None of the subjects had taken part in previous thermal experiments.

Materials

Ten target vehicles were used. These were a utility vehicle (HMMWV), two trucks (2.5-ton cargo truck and 5-ton fuel truck), two tanks (M60 and M1), one M578 recovery vehicle, and four members of the M113 family of vehicles (two M113 armored personnel carriers, an M577 command post vehicle, and an M901 anti-tank missile vehicle). Subjects made their observations of the targets through the thermal sights of six M2 BFVs. Two further BFVs were used. One served as a photography vehicle, so that a record of the thermal appearance of the targets could be maintained; the other was used in an embedded experiment which tested the use of artificial thermal camouflage material. All the BFVs used in the experiment had their ISUs serviced and purged by Direct Support maintenance personnel prior to the experiment. This process included filling the detector-dewar with a silver conductive grease to improve conductivity and the fitting of an improved fuzz-dewar button, which allowed transmittal of the cooling effect more evenly to the detector. These two latter modifications brought the BFVs up to normal Army standards.

Design and Procedure

Experimental design and treatment. The 35 subjects were divided into two groups. The treatment group (17 subjects) was given a class on using the thermal sight prior to the experiment; the control group (18 subjects) relied entirely on their previous training. Ten partly camouflaged targets were placed at varying ranges and positions in a test area. The subjects were required to detect, classify, and estimate the range of the targets at night using the thermal sight. The targets were then moved to different locations within the test area, and the process was repeated so that each gunner had a possibility of detecting a total of 20 targets. The techniques used, the detection rates achieved, and the ability to classify and estimate the range to targets were recorded.

The experiment was conducted over six days. Two days were allocated for setting up the experiment and four days for collecting data. The two set-up days were used to determine the precise positions that targets would occupy on the experimental days, to establish and practice procedures, and to train personnel in data collection techniques. Because each of the 10 targets was to be used twice, two sets of 10 target locations had to be determined. These two sets of target locations are called scenarios A and B. Subjects were tested using scenario A during the first two days of experimentation and using scenario B during the second two days. To ensure that the treatment and control groups were kept apart, the groups were tested on alternating days. The control group was tested on the first and third days and the treatment group on the second and fourth days.

On the morning of the day on which the treatment group made observations in scenario A, they were given a three-hour class on the use of the thermal sight. The class dealt with four topics: sight control manipulation, scanning techniques, classification of detections, and range estimation. Sight control manipulation covered procedures for obtaining a clear thermal image and the need to adjust focus with changes in range. On scanning, subjects were advised to scan with polarity set to white hot and to search the test area by using a series of sweeps in the horizontal plane, with each sweep centered at an increased distance down range, but overlapping the previous sweep. Color slides showing targets as they appear through the thermal sight were used to demonstrate the appearance of a detection, and to teach the subjects the thermal cues that facilitate the classification of detections. The value of switching polarity when attempting target classification was also explained and demonstrated using slides. On range estimation, the difficulties of using the stadia sight to range onto targets that are in partial defilade or camouflaged was made clear, and subjects were advised to use a range card. Both the method of making range cards and the way they should be used in the turret to estimate ranges to targets were reviewed using vu-graphs.

The purpose of the class was to provide information that would enable gunners first, to obtain and maintain a better quality of thermal image; second, to scan more rapidly with a higher probability of detecting targets; third, to classify more accurately the detections they made; and fourth, to estimate the range of those targets with greater precision. Because the subjects were trained gunners with preconceived ideas on the best way to use a thermal sight, it was not expected that all those who attended the class would necessarily follow the recommendations given. The class should therefore be seen, not merely as an attempt to impart knowledge, but also as an attempt to modify established practices.

Test area and vehicle locations. The test area used was to the north and northwest of Bush Hill, Fort Benning, Georgia (grid coordinates GL162828). The sector width covered an angle of approximately 1000 mils (56 degrees) from the observation point and extended out to over 3200 meters. The east or right boundary of the sector was defined by Box Springs Road, which ran north to south. The west or left boundary was defined by a noticeable gap in a ridge. The landscape was heavily wooded and contained three open areas at different ranges that were suitable for target placement. The closest of the open areas was in the eastern part of the test area at between 600 and 800 meters from the observation vehicles and could accommodate up to three targets. The second was to the west at approximately 2000 meters and could accommodate a maximum of four targets. The third was almost in line with the second at between 2900 and 3200 meters and could hold up to three targets. The maximum number of targets per open area was based on a lateral spacing between targets of approximately 100 meters. For each scenario, targets were positioned to give the maximum possible separation the terrain would allow. To help obtain maximum distance between targets, some were also placed just off Underwood Road, which ran diagonally across the test area from southeast to northwest and off Helmet Trail, which ran east to west. The closest targets were at 630 meters and the most distant was at 3150 meters.

For security reasons, target vehicles had to be moved to a holding area at the end of each evening's experimentation. Therefore, when the two scenarios were established on the two set-up days, the exact target positions were marked by stakes so that targets could be repositioned precisely. In addition, SMEs recorded the azimuth and elevation of each target, as it was shown in the turret of each observation vehicle. This ensured that, during experimentation, the researchers knew with certainty which target it was that a subject had detected. The precise range to each target was obtained by using a laser range finder.

The targets were camouflaged to differing degrees using both live and cut vegetation, and some were placed in partial defilade positions. In all cases camouflage was so arranged that the target remained detectable, although not easily detectable, to the observers. Every effort was made to ensure that each target was camouflaged to exactly the same extent on the two nights of each scenario. A photographic record was kept to enable this to be verified later. In addition, a check was made to ensure that the thermal appearance of each target was the same when viewed from each of the six BFVs the subjects would use to make observations. In order to ensure some constancy of temperature of the targets, all had their engines idling during the experimentation. Drivers remained with the target vehicles throughout each experimental period. A list of the targets, their ranges, attitudes to the observers, and type of camouflage, is given for each scenario in Appendix A.

The six M2 BFVs from which observations were made, were placed in a line about 200 feet north and below the crest of Bush Hill. From this position, observers in each vehicle had approximately equal views of the test area. The six BFVs were positioned side by side, with sufficient space between vehicles to allow any two turrets to be rotated toward each other simultaneously without risk of damage to the gun tubes. These vehicles remained in position until the completion of the experiment. Once the BFVs were in position, the thermal sights were turned on and allowed to cool. The quality of the sights was independently rated by two SMEs who then compared findings and agreed on a baseline rating for each sight. Subsequently, the sights were checked at the start and conclusion of each day's experimentation (approximately 7 p.m. and 1 a.m.) and the findings compared with the established baselines. This ensured that any change in sight quality was detected. Although ratings did change marginally from time to time, no one sight was found to have changed disproportionately to the rest during experimentation. The criteria used in making these assessments are given subsequently in the section titled Thermal Sight Classification Techniques.

The BFV that was fitted for through-the-sight photography was located in line with the observation vehicles. The BFV used in the embedded experiment was positioned down range with the targets but was hidden behind a barrier made of thermal reflective material. This vehicle did not constitute part of the main experiment. It was not intended that it should be detectable; and, in fact, it was detected only once. On that occasion, the subject was instructed to disregard it.

Test administration. An SME on the use of the thermal sight occupied the commander's position in each of the six BFVs while subjects were being tested. The SMEs monitored what the subjects saw through the commander's extension to the sight, recorded the subjects' observations, and timed particular operations. Four of the SMEs were research staff, and two were military personnel who had acted as test administrators on previous thermal experiments and who were borrowed for the occasion.

Prior to each evening's experimentation, the area was searched for unplanned heat sources such as exposed rocks that had become heated by the sun. It had been hoped that such heat sources would exist, because they would test the ability of subjects to distinguish between real and false targets. Ways to differentiate real from false targets had been taught as a part of classification techniques in the thermal class. Surprisingly, in view of experience on earlier experiments, no unplanned targets were observed on any of the nights.

On each night, experimentation began at 8 p.m. and ended no later than 1 a.m. Subjects were tested six at a time (e.g., one per observation vehicle). Each subject required approximately one hour in the turret to make his observations in each scenario. Therefore, a maximum of three subjects made observations from each vehicle each night. Because it was realized that changes in humidity might have affected the quality of thermal image as each evening progressed, it was arranged that subjects who entered the turret first in scenario A would be second in scenario B; and those who had been second in scenario A would be third in B.

Prior to each subject entering the turret for experimentation, the SMEs deliberately mis-set the major thermal sight controls. The focus, contrast, and brightness knobs were all rotated to their right stops. This enabled the SMEs to measure the time it took the subjects to obtain a first clear thermal image from a common baseline.

Test Schedule. The test schedule employed and sequence of events experienced by the subjects was as follows:

Sunday, November 2, 1986: The range was set up for scenario A. Procedures were checked and the experimental assistants were trained in data collection techniques.

Monday, November 3, 1986: The range was set up for scenario B. Procedures were checked, and the training of the experimental assistants was continued.

Tuesday, November 4, 1986: The subjects in the control group arrived at 1 p.m. They were briefed on the sequence of events they would experience in the course of the day and were divided into six groups of three subjects. Each sub-group of three was allocated to one of the SMEs, who explained that he would be with them in the turret to record data during experimentation.

Between 2 p.m. and 4 p.m., each soldier was given an opportunity to make a range card. Each subject was taken individually to the BFV he would be using, and the sector limits were pointed out. He was allowed up to one hour to make a range card; as it happened, nobody took this long. All the necessary equipment was provided, including a Fort Benning standard range card form and topographic map (1:50,000). The thermal sights of the BFVs were turned on and made ready for use so that the subjects could examine the area both thermally and optically if they wished. Once the range cards had been made, they were kept in the BFVs to ensure that they would be available in the evening during the experiment.

When the range cards had been made, the subjects were moved out of the area and the targets were placed in position and camouflaged as required for scenario A. A check was made to ensure that each target was equally detectable from each observation vehicle, the area was checked for unplanned targets, and then the controls of the thermal sights were deliberately mis-set preparatory to the subjects' return.

The first six subjects were brought to the BFVs at approximately 8 p.m. The SME in each turret amplified the initial briefing. He explained that the subject's first task would be to obtain a clear thermal image on the sight and warned him that the sight controls had been mis-set. He then explained that once the sight was set up ready for use, he should scan the sector for targets. When a possible target was detected, he should stop scanning and announce the fact by saying target. He should then try to classify the target and give an estimate of range before moving on to the next target. The subject was warned that the SME would be taking notes during the experiment, timing certain operations, and that there would be a questionnaire to be completed at the end of the experiment. He was also told that he had one hour to search the area for targets, that it was not a speed test, but that if the subject believed he had detected all the targets before the hour had elapsed, he could announce the fact and stop. The subjects did not know how many targets existed or the types of vehicles that had been placed as targets. The SMEs were instructed not to prompt, help or assist the subjects in any manner that might prejudice the results.

Each subject received his range card, entered the vehicle, obtained an initial thermal image, and began his search. When the first six subjects had completed the test, they were taken to a separate holding area so that they had no contact with the next six subjects. When all 18 subjects had been tested, they were returned to their garrison.

The thermal sights were then rechecked to ensure no degradation of image had occurred. The targets were driven to the security holding area and experimentation was concluded for the day.

Wednesday, November 5, 1986: The treatment group was tested using scenario A. With the exception of the three hours of classroom instruction on using the thermal sight that had been given in the morning, the events for the treatment group were identical to those for the control group.

Thursday, November 6, 1986: The control group returned at 8 p.m. Scenario B had been set up, sights cooled and classified, and the area scanned for unplanned targets. The six subjects who had been last into the turret on Tuesday (scenario A) were tested first, followed by the six who had been first in scenario A. Subjects were given their range cards on entering the turret, and testing proceeded as on the previous occasion.

Friday, November 7, 1986: The treatment group returned at 8 p.m. Again, as with the control group, scenario B had been set up, sights cooled and classified, and the area scanned for unplanned targets. As on all previous nights, no unplanned targets were visible. However, one unscheduled vehicular target was in the sector; this was the M578 that had broken down. Whenever a subject detected this, he was instructed to disregard it and to continue searching for other targets. With this exception, the testing proceeded as it had for the control group.

The weather remained clear with no precipitation throughout the four days of experimentation. Temperatures ranged in the 60s and 70s degrees (F), and relative humidity was generally between 80 and 90 percent by the end of each evening's experimentation. Precise temperature and humidity readings obtained from the nearest weather station are given in Appendix B. The SMEs in the BFVs reported that they did not notice any change in clarity of thermal image as each evening progressed, and subsequent analysis revealed no pattern of declining number of detections.

Results

Introduction

Some difficulties arose in operationalizing the experimental design. First, the test area was found to be too narrow, and with insufficient open space to ensure that all detections were independent. The SMEs confirmed that on occasions subjects had up to three targets in view concurrently, although analysis showed that the subjects did not always realize this. Second, while maximum separation between targets was obtained in scenario A, to obtain the same degree of separation in scenario B, some targets had to be located close to scenario A positions. This may have facilitated target detection in scenario B. Third, there is evidence in the data that subjects discussed and compared their performances during the 48 hours between scenarios. As a result, several subjects in the control group showed marked changes in scanning technique in scenario B. Fourth, the data for two subjects were discarded for scenario B: one because he had been awake for 40 hours at the start of experimentation; the other, because it was found that he had been put on security detail, and therefore had learned the number and types of targets to be used in scenario B. These difficulties are discussed in greater detail in Appendix C. For the reasons given above, the data collected in scenario B are judged to be unreliable. Therefore, where scenario B data is reported, it should be treated with caution. Where results differ between scenarios, those from scenario A will be given greater weight.

The results will be presented in four sections. The first will be concerned with obtaining an initial thermal image, the second will deal with scanning techniques, the third with range estimation, and the fourth with classification of detections. Some discussion is incorporated an the end of each section to facilitate comprehension of ensuing sections.

Initial Thermal Image

When the subjects entered the turret for the experiment, the thermal sights had already been switched on and allowed to cool and the controls had been deliberately mis-set. Subjects were warned of this and told that their first task was to bring up the best thermal image they could obtain. It was predicted that the sequence of actions taught in the thermal class would let the treatment group perform this process more quickly. However, it must be acknowledged that the use of color slides in the class may have caused some subjects, despite their experience, to form a new and better impression of the clarity of thermal image that could be obtained. Any such new realization of the potential of the sight may have resulted in subjects being more thorough than they would otherwise have been, and hence taking longer. The essence of the system of adjustment taught in the thermal class was that, with the sight set to low magnification, subjects should first obtain a coarse adjustment of contrast and brightness, then focus the sight, and finally fine-adjust contrast and brightness.

Analysis showed that even though the treatment group was on average faster than the control group in obtaining an initial image, the difference between the groups was not statistically significant. In fact it was not the average times, but the variability in the times taken to obtain an initial image, that was the surprising aspect of the findings. The means, standard deviations, and ranges of the times taken to obtain an initial focus are given in Table 1.

Table 1

Means and Associated Standard Deviations and Ranges Found for the Times Taken to Obtain an Initial Focus for Each Group in Each Scenario.

	SCENARIO A		SCENARIO B	
	Control Gp.	Treatment Gp.	Control Gp.	Treatment Gp.
	N=18	N=17	N=17	N=16
Mean Time to Initial Focus	201	160	156	109
Standard Deviation	202	83	136	56
Range	570 (30 to 600)	317 (67 to 384)	540 (60 to 600)	165 (60 to 225)

Note. All times are in seconds and are rounded to the nearest second.

The differences between the two groups in terms of variability of time taken, whether this is expressed by range or by standard deviation, were substantial in both scenarios. As may be seen in the table, the subjects in the control group took between 30 seconds and 10 minutes to obtain an initial focus. In the treatment group, the slowest person in scenario A took 6 minutes 24 seconds and the slowest in scenario B took 3 minutes 45 seconds. Interpreting these results, we may say that the treatment group appears to have been more consistent in the times they took to achieve an initial focus than were the control group. To test whether this apparent difference in degree of consistency was significant, the variances found for each group were compared for each scenario using a test for homogeneity of independent variances. In both scenarios, the differences were significant (Scenario A; $F(17, 16) = 5.926$, $p<.01$. Scenario B: $F(16, 15) = 5.773$, $p<.01$).

These findings indicate that the subjects in the treatment group were more consistent in the times they took to achieve an initial focus than were those in the control group, and this improved consistency is attributable to the information received in the class. Post-experiment discussion with the SMEs suggested that the wide range of times found with the control group arose, at least in part, from the existence of two sub-groups. Some subjects began to scan with very inferior images and only sharpened and refined them when they had made their first detection. These were therefore recorded as taking a very short time. Others had difficulty in obtaining the initial image, particularly with adjusting the focus knob. They took a long time. From a military viewpoint, neither of these is desirable. In that the thermal class taught a satisfactory procedure and provided a standard of image clarity with which the subjects could compare their own attempts, it may be concluded that this aspect of training was successful.

Scanning Techniques

The class given to the treatment group recommended scanning with polarity set to white hot and scanning in a systematic pattern in which the sector is searched by a series of overlapping sweeps in the horizontal plane. The techniques used by the subjects were recorded and rated according to how closely they approached the recommended techniques. For both polarity usage and scanning pattern adopted, rating was on a three-point scale, where three points indicates the recommended technique was used, two points indicates it was used some of the time, and one point indicates it was not used at all. These ratings facilitated analysis of the data. For polarity usage, the definitions of ratings were as follows: a rating of 3 indicated that the subject scanned in white hot (WH) only; a rating of 2, that he scanned in both black hot and white hot (WH/BH); and a rating of 1, that he scanned in black hot (BH) only. Similarly, search patterns were divided into three categories: a rating of 3 indicated systematic scanning in the horizontal plane only (H-S); a rating of 2, that the subject used some other systematic scanning technique that could include limited scanning in the horizontal plane (O-S); and a rating of 1 indicated erratic scanning (E-S). The number of gunners in each group using the different techniques are shown in Table 2.

Table 2

Number of Gunners in Each Group Using the Specified Scanning Techniques

	Scenario A		Scenario B	
	Control n=18	Treatment n=17	Control n=17	Treatment n=16
Polarity				
WH	9	15	10	13
WH/BH	4	2	6	3
BH	5	0	1	0
Scan Pattern				
H-S	8	11	8	10
O-S	2	4	3	3
E-S	8	2	6	3

Techniques used by the control group. In Table 2, it may be seen in scenario A that 9 of the 18 subjects in the control group scanned with polarity set to white hot and 5 with it set to black hot. However, in scenario B, only 1 scanned in black hot and 16 of the 17 scanned in white hot at least some of the time. As was noted earlier, this change is believed to result from the gunners exchanging information about their performance and techniques between scenarios. For this reason, the techniques used by the control group in scenario A better reflect the range of techniques that may be expected to be found among gunners in general. The inference that may be drawn is that while most gunners prefer white hot, a significant proportion (in this sample 50 percent) will scan in black hot at least part of the time.

The variety of scanning patterns used by the control group in scenario A was great and included: scanning in the horizontal plane; scanning in the vertical plane; square wave pattern scanning (a combination of alternating vertical and horizontal movements of the sight where each horizontal movement took the gunner's view a little further across the sector); and block scanning (selecting one part or block of the sector, searching within it in an erratic manner, and then moving on to the next block). Finally, some gunners appeared to scan in an unsystematic manner; that is, the sight was centered on one point of interest, then swung to another, each movement being dictated by whatever happened to catch the gunner's eye.

It was noted by the SMEs in the turrets that when a vertical scanning pattern was used, as the gunners elevated the sight to look further into the distance, they rarely adjusted the focus, and so image definition was lost. This loss of definition may explain why on two occasions two of the gunners spent some time scanning the sky.

Effectiveness of the thermal class in changing scanning patterns. As was expected and is shown in Table 2, not all the gunners who attended the class followed the recommendations given. In scenario A, 2 of the 17 subjects scanned with polarity set to black hot for part of the time, and 6 scanned using a non-recommended pattern. Also as expected, some of the subjects in the control group already used the same techniques as were taught in the class. Nine scanned in white hot and 8 used a systematic, horizontal-plane scanning technique. In fact, 6 subjects in the control group scanned precisely as had been recommended in the class. We may reasonably infer that a similar proportion of the treatment group would also have used the recommended techniques if left to their own devices.

Because the subjects were all experienced gunners with established ideas on how the thermal sight should be used, the class is best thought of as an attempt to alter established sight usage practices for those who would normally have used other techniques and reinforcement for those who already used the techniques taught. The effectiveness of the class as a method of teaching and/or reinforcing particular scanning techniques was tested by taking t-tests between the ratings of polarity usage and scanning technique found for the control and treatment groups.

Because the ratings are on three-point scales, where 3 is using the recommended techniques all the time and 1 is not using them at all, the closer the mean rating for a group approaches a value of 3, the greater the number of persons in that group using the recommended techniques, and the closer it approaches a value of 1, the greater the number using other techniques. The means of the ratings for polarity usage and for scanning technique that were found for each group in scenario A are given in Table 3, along with the results of the t-tests taken between the groups.

Table 3

Means of the Ratings for Polarity Usage and Scanning Techniques Found for the Control and Treatment Groups in Scenario A

	Means of Ratings				
	Control Gp. n=18	Treatment Gp. n=17	t-value	df	p
Polarity usage	2.22	2.88	2.907	33	< .005
Scan Pattern	2.0	2.53	1.827	33	< .05

As may be seen in Table 3, and as predicted, the mean ratings found for the treatment group were significantly higher than those found for the control group for polarity usage and scanning pattern. From this we may conclude that some modification of established scanning techniques did occur and therefore that the class was effective. The greater use of white hot polarity by the treatment group was probably a result of the visual reinforcement provided by the color slides of thermal images that were shown in the class. These slides demonstrated dramatically that targets were more easily detected in white hot.

Effectiveness of the recommended scanning techniques. The experimenters hypothesized, and had reason to believe from earlier experimentation, that the techniques taught in the class would improve performance in sector scanning. In fact, in scenario A, 6 subjects in the control group and 9 subjects in the treatment group used precisely these techniques. To test the effectiveness of the techniques themselves, the performance of these 15 subjects was compared with that of the 20 subjects who deviated in some manner from them.

Two performance measures used were the number of detections made by each subject and the overall time spent by each subject scanning for targets. Scanning time was recorded by the SMEs in the turrets and was defined as the total time spent sweeping the area for targets until the subject said he was content that no more targets existed. It does not include time spent consulting the range card or time spent trying to classify a detection.

The average number of targets detected and average time spent scanning by subjects in each group are shown in Table 4, along with the results of t-tests taken between the groups. As Table 4 shows, in scenario A, those who used the recommended techniques detected on average 9.53 of the 10 targets, whereas those who did not detected 8.25. The difference between the means is statistically significant. In scenario B, 13 subjects used the recommended techniques and, on average, detected 9.38 of the 10 targets; whereas those who used other techniques detected on average 8.4 of the targets. Again the difference between the means is statistically significant.

In both scenarios, scanning time was significantly less for the group using the recommended techniques. In scenario A, those who used other techniques took, on average, 587 seconds to complete their scanning of the sector compared with 321 seconds for those who used the recommended techniques. This is equivalent to a 45 percent reduction in time. In scenario B, the figures are 645 seconds for the group who used other techniques and 291 seconds for those who used the recommended techniques, a reduction in scanning time of better than 50 percent. Those who scanned in white hot and who used a systematic search pattern in the horizontal plane, detected a significantly greater number of targets and spent significantly less time searching for them than did those who used other techniques.

Table 4

Mean Number of Targets Detected and Mean Scanning Times Found for Each Group in Each Scenario, and the Results of t-tests Between the Groups.

SCENARIO A	Recommended Techniques n=15	Other Techniques n=20	t-value	df	p
Mean Number of Detections Made (Max = 10)	9.53	8.25	2.308	33	<.025
Mean Scanning Time (Seconds)	321.1	587.2	1.785	33	<.05
SCENARIO B	**Recommended Techniques n=13**	**Other Techniques n=20**	**t-value**	**df**	**p**
Mean Number of Detections Made (Max = 10)	9.38	8.40	2.815	31	<.005
Mean Scanning Time (Seconds)	291.3	644.8	2.001	31	<.05

Based on the previous findings, further analyses were performed to determine if incorporating both white hot scanning and the recommended scanning pattern resulted in more detections than employing either technique separately. For example, if gunners were able to detect more targets by scanning in white hot, would their subsequent adoption of the recommended scanning pattern lead to a second and further improvement in the number of detections they made? The 35 subjects who took part in scenario A were treated as a single sample, and their performance results were regressed onto the scanning techniques they used.

When detections were regressed on polarity and scanning pattern, both techniques were shown to contribute significantly to the numbers of targets detected. The regression analysis table is shown in Appendix D. Partial F-tests showed that when gunners were using white hot polarity, the additional use of the recommended scanning pattern led to a further significant increase in number of detections made. Similarly, when gunners were using the recommended scanning pattern, the additional use of white hot polarity also led to a further significant increase in the number of detections made. It is therefore concluded that both the polarity used and the scanning pattern adopted contributed significantly to the number of detections made. In fact, as the coefficient of determination for the multiple regression shows, 44 percent of the variability in the detections could be explained by knowledge of only the scanning patterns and polarity used by the gunners.

In a similar manner, the times spent in scanning the sector were regressed onto the scanning techniques used. The regression analysis table is given in Appendix E. The regression of scanning time on polarity showed that choice of polarity significantly affected the time taken to scan the sector and, in fact, that 28 percent of the variability in scanning times could be explained by knowledge of the use of polarity. However, no relationship could be shown to exist between the scanning pattern selected and the time taken to scan the sector.

To summarize, because the use of the recommended scanning pattern ensured complete coverage of the sector, its use significantly increased detection rates; and because the use of white hot polarity makes targets easier to detect, the number of detections made increased and the search time was reduced.

Conclusion to scanning techniques. The results have demonstrated two points. First, the thermal class was an effective method for modifying and/or reinforcing the use of particular scanning techniques employed by experienced gunners. Second, the techniques that were taught were effective because they both reduced the time required to scan a sector and increased the number of targets detected. These findings are for targets that had been partially camouflaged and were located in or close to open areas in a heavily wooded terrain. It is not known whether the finding on polarity usage can be generalized to other, more extreme terrains and climatic conditions such as tundra and desert; further experimentation would be required to determine this. However, the results should be able to be generalized to most temperate climatic zones, which would of course include central Europe.

Range Estimation

The exploratory research had shown that range estimation to camouflaged targets detected using the thermal sight was difficult. If the target is in the open and its shape can be clearly distinguished, then the stadia sights can be used; however, when the target is partly screened by vegetation or is in partial defilade, this becomes much more difficult. Ideally, a laser range finder would answer the problem, but the BFV is not so equipped. Therefore, it was hypothesized that more reliable estimates would be made if gunners were encouraged to make greater use of range cards. To this end, the thermal class taught the importance of making an accurate range card and of using it to determine the range of targets detected through the thermal sight.

The analyses given below address two questions. First, was the class effective? That is, did those who attended produce better range cards, and did they make greater use of them in the turret? Second, was the technique effective? That is, did those who produced good range cards and who made use of them in the turret, estimate range more accurately?

All the subjects made range cards; however, post-experiment sorting of the data collection documents showed that three of the range cards for the control group were missing and a fourth lacked a subject identification code. In addition, one subject did not make any estimates of range for the targets he detected. For analysis purposes, the control group was reduced from 18 subjects to 13 where the quality of range card is related to accuracy of range estimation and to 17 for all other range-related analyses. Data for the treatment group were complete for all 17 subjects.

Effectiveness of the thermal class. The quality of the range card produced by the subjects was the first of the measures used to assess the effectiveness of the class. Because the need to produce an accurate range card was emphasized in the class, it was expected that the treatment group would make a greater effort to do so. The quality of the range cards was judged by three SMEs using a three-point scale. Three points indicated that the range card was good, i.e., it was of sufficient accuracy and detail for it to be handed to a different gunner and to expect him to be able to use it effectively. Two points showed that the range card was adequate, i.e., it was of sufficient accuracy for it to be used by its maker with reasonable effectiveness, but that it lacked the detail and information necessary for another gunner to be able to take it over. One point indicated that the range card was unusable, i.e., if the gunner were to attempt to estimate range using it, his estimates would be very inaccurate. When the judgments were made, the range cards from the two groups were intermingled and given to the SMEs as a single batch so that they had no knowledge of which cards belonged to which group. The three SMEs made their judgments separately and independently; subsequently, the scores they had allotted were totaled for each range card, giving a possible score range of three to nine points. The mean point scores for the quality of range card found for the treatment and control groups are given in Table 5, along with the results of a t-test taken between them.

Table 5

Mean Point Scores Found for the Quality of Range Cards

	Control Gp. n = 13	Treatment Gp. n = 17	t-value	df	p
Mean Point Score for Range Cards (Max=9, Min=3)	4.15	5.53	2.471	28	$<.01$
Range of Scores	3 to 6	3 to 9			

As the mean values in the table show, those who had attended the class produced a significantly better quality of range card than those who had not. The treatment group achieved a mean point score of 5.53, indicating two out of the three SMEs judged the average range card produced by this group to be adequate. This interpretation is supported by the observation that the most frequently awarded (modal) point score for the treatment group was 5. For the control group, the mean point score was 4.15 and the modal score was 3, indicating that the most frequent assessment made by the SMEs of the range cards from the control group was unusable.

The amount of time each subject spent consulting the range card was the second measure of the effectiveness of the class. A count was kept of this by the SMEs in the turrets. The average time spent by subjects in the treatment group consulting the range card was 106.5 seconds in scenario A and 46.4 seconds in scenario B. For the control group, it was 90.8 seconds in scenario A and 62.8 seconds in scenario B. The differences between the groups are slight and do not approach statistical significance in either scenario. Closer examination of the data in scenario A showed that of the 17 subjects in the treatment group, 3 never consulted their range cards at all and 8 consulted them for a total of 1 minute or less. Of the 17 in the control group, 6 never used their range cards and 7 used them for one minute or less. In total, only 6 subjects both made a range card of adequate quality (minimum of 5 points awarded) and used the card for more than one minute in the turret. Two of these were from the control group.

In summary, the results indicate that the part of the class dealing with range estimation by using the range card was ineffective. Moreover, because so few used the recommended techniques, the effectiveness of the technique itself cannot be reasonably evaluated with the data available.

It is not known why the gunners did not make use of range cards in the way they had been taught. It may in part be because they were not in the habit of using range cards in the turret and, being experienced, had confidence in their abilities to estimate range without the card. Certainly, the instructor reported subsequently that there had been some resistance on the part of the subjects to the idea of using the range card in this way. A second possibility is that in making the range card the gunners had effectively memorized it, so that they had no need to refer constantly to it. If this were true, then one would expect that those who made the better range cards would also estimate range more accurately. To test this, the average percentage error in range estimation found for each gunner in the treatment group was correlated with the quality of the range cards produced. The degree of correlation found was small ($r = -.18$). In view of this, the most probable explanation for the gunners' failure to use the range card in the turret was their resistance to the idea.

Accuracy of range estimation by groups. Assessments of the accuracy of range estimation must take into account the range of the target. A gunner who can estimate to within 300 meters the range of a target at 3000 meters has done better than a gunner who estimates to within 300 meters the range of a target at 600 meters. For this reason, the accuracy of range estimation was assessed in this analysis by taking the difference between the estimated and actual ranges of each target and expressing this difference as a percentage of the actual range to the target. Thus an estimate of 900 meters for a 600-meter target, which is an error of 300 meters, would be expressed as a 50 percent estimation error because it is 50 percent of the actual range to the target. To see whether those in the treatment group estimated the distance to targets more accurately than those in the control group, the mean percentage error of estimate was calculated for each subject over the number of targets detected by each subject in each scenario. The results are shown in Table 6.

Table 6

Mean Percentage Errors of Estimate by Group Across Scenarios

SCENARIO A	Control Gp. n = 17	Treatment Gp. n = 17	t-value	df	p
Mean Percent Error of Estimate	52.6	38.3	2.2742	32	<.05
SCENARIO B	Control Gp. n = 16	Treatment Gp. n = 16	t-value	df	p
Mean Percent Error Error of Estimate	50.1	43.6	0.983	30	NS

In both scenarios, the treatment group estimated the range of targets more accurately than did the control group. However, this improvement only reached statistically significant proportions in scenario A. In scenario A, the average percentage error of estimate for the treatment group was 38 percent, which extrapolates to a 383-meter average error for targets at 1000 meters and a 1149-meter error at 3000 meters. For the control group, the equivalent values would be 526 meters at 1000 meters and 1578 meters at 3000 meters.

The reason why the treatment group should have estimated range more accurately is not clear. It has been established that accuracy of range estimation did not relate to either quality of range card produced or to the time spent consulting the range card. It is possible that as a result of the class the gunners focused their sights a little better and so were able to make more precise estimates; equally, it may be that, quality of range cards apart, the gunners did pay more attention to the landscape and so formed a more accurate picture of distances to salient features. However, perhaps the simplest explanation is that, as a result of the class, the subjects in the treatment group were both forewarned that they would be expected to estimate range and were motivated to try harder to do so accurately. This explanation would also serve to explain the better quality of range cards the treatment group produced.

Accuracy of range estimation in general. The experiment also yielded information on the accuracy with which gunners can estimate the range of partly camouflaged targets at night using the thermal sight. If we accept that the better range estimation by the treatment group reflects motivational factors rather than being the result of changes in technique induced by the treatment, then the two groups can be treated as a single sample and the scenarios combined. (Questions about the reliability of data from scenario B are not applicable to range estimation.)

a) Close targets. Of the 20 targets used in the two scenarios, five were located at a range of 630 meters. The 35 subjects made a total of 155 estimates of range for these five targets. Three of these estimates put the range at less than 500 meters, 16 put the range at between 500 and 750 meters, and the remaining 136 estimates placed the targets at greater distances. The average of the 155 estimates was 1188.6 meters, with a standard deviation of 451.4 meters. This means that the average estimate of range for these targets was 189 percent of the actual range. From these figures, it is clear that there was a marked tendency to overestimate the range of near targets. In fact, 42 of the 155 estimates (27 percent) put these near targets at a range of 1500 meters or greater.

b) Far Targets. Four targets were located between 3050 and 3150 meters. A total of 98 estimates of range were recorded for these four targets. Twenty-nine of these estimates (30 percent) put the range at between 3000 and 3200 meters. No gunner estimated the range to be greater than 3200 meters. The average of the estimates made was 2312 meters, with a standard deviation of 578 meters. This means that the average estimate was 75 percent of the actual distance to the targets. It was also noted that for the far targets, 22 of the 35 subjects (63 percent) underestimated the range, on at least one occasion, by one kilometer or more.

To summarize, the gunners tended to overestimate the distance to near targets and underestimate the range to far targets (of the 583 estimates recorded, 339 (58 percent) were between 1000 and 2000 meters, even though this area contained only 30 percent of the targets). It should be understood that the findings on range estimation do not in any way constitute a criticism of the range estimating abilities of the gunners involved in the experiment. To estimate the range to a partially camouflaged target that has been detected thermally is extremely difficult. The gunner is viewing a screen that provides a two-dimensional, magnified view (x4 or x12) of the external landscape on which he can see the thermal image of a part of a target. If he can classify the detection, then he can perhaps estimate its size relative to nearby objects, but he must then be able to assess the range of the nearby objects. Or, he can attempt to fit his mental extrapolation of the actual whole vehicle shape to the stadia sight; however, in doing so he is relying heavily on his imagination and his memory. Given that the BFV has no laser range finder, the gunner is left with an unenviable task. It was for this reason that the researchers suggested making greater use of the range card in the turret. If detections can be placed relative to features in the landscape that are marked on the range card, and hence are at known distances, then gunners can make range estimates irrespective of whether they can classify the detections. Theoretically, the method should work, but because the subjects were not convinced of the need for the method, the intended test did not occur.

Classification of targets

In the context of the experiment, classification was defined as determining whether the targets detected were tracked or wheeled vehicles. Time was given in the thermal class to classification, and the gunners who attended were instructed to switch polarities when trying to classify targets in order to bring out the shape of the target, to look for engine location, and to count road wheels if these could be seen. These points were emphasized by the use of color slides of sample target vehicles. It was therefore predicted that those who attended the lecture would prove to be better at classifying targets than those who did not.

Clearly, a gunner had no opportunity to classify a target if he had failed to detect it. Therefore, for analysis purposes, the number of correct classifications made by each gunner was expressed as a percentage of the number of detections he had made. Analysis showed that in fact there were no significant differences in correct classification rates between the two groups. The gunners in the control group on average correctly classified 56 percent of the detections they made in scenario A and 50 percent in scenario B. The gunners in the treatment group on average correctly classified 53 percent of their detections in scenario A and 56 percent in scenario B.

As would be expected, it was generally found to be more difficult to classify the more distant targets. Because the degree of camouflage varied from target to target, a precise picture of the increasing difficulty gunners experience in classifying targets with increasing range cannot be given. However, assuming the degree of camouflage was randomly distributed, and taking the performance of both groups together in both scenarios, the following figures give some indication. For the eight targets at between 630 and 1450 meters, 70 percent of detections were followed by correct classifications. For the eight targets at between 1850 and 2400 meters, 44 percent of the detections were followed by correct classifications; and for the four targets at greater than 3000 meters, 30 percent of the detections were correctly classified.

Discussion

Thermal training class. The thermal training class was shown to be an effective instrument for modifying and/or reinforcing the current practices of experienced gunners in the following two areas: sight control manipulation and scanning techniques. It was not effective in persuading gunners to use the range card to estimate range. The probable reason for this has been suggested to be resistance by the gunners to the idea. In the first two areas (sight control manipulation and scanning), the instructor was able to demonstrate the value of the points he was making by showing color slides of thermal images. The clarity of image that could be obtained and the advantages of using white hot polarity to scan were therefore made obvious to the audience. For the range estimation technique, no such visual proofs were available. The instructor was therefore constrained to demonstrate the advantages theoretically; and for the experienced people who constituted the audience, this was clearly not enough.

No evidence was found that could demonstrate whether the teachings on target classification were effective. This was because, contrary to expectations, there were no false or unplanned targets down range. Effectively, therefore, classification in this experiment was limited to distinguishing between tracked and wheeled vehicular targets. Gunners did not need to determine whether a detected heat source was of military significance; all detections were targets. However, part of the information given in the class had covered distinguishing false targets from real ones. The efficacy of this part of the class therefore remains untested.

<u>Effectiveness of the techniques</u>. Clear evidence was found that the sight control manipulation techniques taught in the thermal class were beneficial. The increase in consistency (i.e., reduction in variability) of the time required to obtain an initial thermal image is indicative of a more precise and thorough technique. That is, it ensures that the image that is obtained is clear and is obtained in a reasonable time. Based on the figures found in scenario B of this experiment, when subjects had some practice, one would predict that by using this technique 80 percent of gunners would achieve initial focus within 2 minutes and 45 seconds. For gunners using the variety of techniques found with the control group, the equivalent time would be 4 minutes and 52 seconds. The report of the SMEs that some gunners in the control group began scanning before they had achieved a clear thermal image and only fine-tuned once they had made their first detection is of concern. This technique may cause a gunner to fail to detect a well-camouflaged target. Therefore, it is argued that there is a need for a clear-cut procedure for obtaining an initial thermal image and a need for a standard defining the clarity of that image. In view of the results, it may reasonably be suggested that the procedures taught in the class, together wi the color slides to provide the standard, meet this need.

The effectiveness of the scanning techniques taught was also clearly demonstrated. The use of both white hot polarity and a systematic horizontal plane scanning technique significantly increased the number of detections made. The use of white hot polarity also led to a significant reduction in scanning time. Scanning with polarity set to white hot is consistent with current teachings at Fort Benning. It was therefore surprising to find so many in the control group scanning in black hot at least part of the time. This may reflect training received at an earlier period, or it may reflect an inconsistency in training. The recommendation that gunners scan in the horizontal plane by a series of overlapping sweeps of the sector has two obvious advantages: first, it ensures that the whole sector is thoroughly scanned; and second, for reasonably level terrain, it minimizes the need to adjust the focus during each sweep. One proviso should be added to the otherwise clear-cut findings on scanning techniques. The experimental test was conducted in a mixed woodland area. It is not known to what extent the technique of scanning can be generalized to other climatic zones such as desert or arctic areas.

The effectiveness of the range estimation technique taught in the class could not be assessed because an insufficient number of subjects used it. Clearly, if this method is to be tested, a separate experiment will be required in which a group of gunners trained in the method are compared with control group(s) trained to an equal extent in other techniques. Given the accuracy of range estimation found in this experiment (average error of estimate for all subjects over all targets in both scenarios equals 46 percent of distance to target), there is a need for improved and/or different training or the inclusion of range finding equipment in the BFV.

The adequacy of the classification guidelines were also not effectively tested in this experiment. Primarily, this was because there were no false targets in the field of view. In future experiments, the desirability of deliberately including both false targets and a greater variety of military targets should be considered. This is because classification is a more complex process than was tested in this experiment. Gunners must be able to distinguish troop movements and fortified positions from vehicles in and along tree lines and to distinguish all of these from non-military heat sources such as animals and agricultural/civilian equipment.

General findings. The theme underlying this experiment was to determine the impact of partial camouflage on the ability of trained personnel to detect, classify, and estimate the range of targets. Taking the experiment as a whole, detection rates varied between 84 percent and 95 percent, depending on the group and the scenario. Bearing in mind the limited size of the sector, the established fact that all targets were detectable, and that one hour was allowed for scanning, it is up to others to determine whether these detection rates are satisfactory.

No target went undetected, and several of the subjects detected all the targets. In view of the fact that targets were placed out to ranges in excess of 3000 meters, this speaks well of the capabilities of the thermal sight, a point reinforced by the observation that 30 percent of the detections at these far ranges were followed by correct classifications.

Regarding correct classification of targets, it may generally be said that for this sample of gunners 2000 meters was a pivotal distance. For partially camouflaged targets below 2000 meters, correct classification occurred more than 50 percent of the time, whereas for those above 2000 meters it occurred less than 50 percent of the time. Greater precision cannot be given in these findings because the degree of camouflage was not standardized or recorded.

There is a very real need for a methodology or a device to help gunners estimate the range of partially camouflaged targets. It is a demanding task because it is often difficult to tell how much of, or even what part of, a target one is seeing. This makes it hard to accommodate the target in the stadia sight. The problem is compounded by heat bloom on nearby foliage. Indeed, on two occasions gunners were observed to fit the heat bloom on the vegetation behind the M1 tank into the choke sight. Coincidentally, it gave them almost precisely the correct range, 3000 meters.

Implications for thermal training. The performance of the control group in the experiment demonstrated and confirmed the need for thermal training guidelines in three areas. These are obtaining an initial thermal image, scanning, and range estimation. The performance of the treatment group demonstrated the effectiveness of the training guidelines developed in the first two of these areas. The third remains untested. In the light of the experimental findings, the previously established guidelines were reworked wherever possible into formal procedures and assembled into a single, reproducible handbook that could be used for on-the-job training. In addition, a slide presentation was prepared that would teach BFV crew about the capabilities of the thermal sight, familiarize them with the thermal appearance of detections, and would provide examples of thermal cues that facilitate classification. The handbook and slide presentation together constitute a basic thermal training package. This package is described separately in the following section.

THERMAL TRAINING PACKAGE

The thermal training package comprises a handbook and a slide presentation with accompanying script.

The Handbook

The handbook contains the following:

- An introduction describing in simple terms how the thermal sight works.
- A brief review of the thermal controls, stating their purpose and with an accompanying diagram showing their appearance and location.
- A step-by-step procedure for obtaining an initial thermal image.
- A procedure that will let a gunner pre-mark the controls so that an initial thermal image can be obtained rapidly and easily.
- A procedure for scanning a sector.
- A procedure and guidelines that tell a gunner what to do when he detects a heat source and that guides him in classifying it.
- A set of guidelines on estimating range using the thermal sight.

The introductory section and overview of the controls provide a new gunner with a basic understanding of the nature and purpose of a thermal sight and an understanding of its limitations. The first procedure given in the handbook presents the information required to obtain an initial thermal image. It is essentially the same as that taught to the thermal class in the experiment reported above, but has been reworked into a precise step-by-step procedure. This new procedural format was tested experimentally; the experiment and the results are reported in the next section. The second procedure given in the handbook grew out of the first and is a method for marking some of the settings on the controls of the thermal sight so that gunners can pre-set them while the sight is cooling. It makes obtaining the thermal image both easier and quicker. The third procedure, that for scanning a sector, incorporates the techniques that proved so successful in the thermal experimentation reported above.

The final two sections of the handbook deal with the classification of detections and with range estimation. These two sections, for reasons already given, lack experimental support and are therefore termed guidelines. They are, however, included in the handbook for two reasons. First, they do not conflict with accepted practices; and second, there is clearly a need for guidelines, especially in the area of range estimation.

The Slide Presentation

The slide presentation comprises 28 color slides with accompanying script. It is designed to show new gunners how targets will appear through the thermal sight and to build an initial understanding of how to interpret thermal images. The presentation is arranged so that subjects see a target first as it appears through the day sight in daylight and then as it appears in thermal. The slides cover the appearance of the thermal landscape, detections in low magnification, and the effect of switching to high magnification and of changing polarity. They point out thermal cues that aid target classification and show targets at ranges from 630 meters to 3150 meters. Some of the targets are partly camouflaged and some in the open. The slides are of good quality and will serve as a standard to teach the clarity of image that can be achieved with a well-adjusted sight.

Test of Initial Thermal Image Procedure

The method of obtaining an initial thermal image that is given in section III of the handbook was successfully taught and tested in the thermal experiment reported earlier. Subsequently, it was reworked into a precise step-by-step procedure so that it could be more easily used to provide field training to new gunners. The procedure was then tested experimentally to ensure, first, that it was readily understandable; second, that it worked; and third, to obtain the opinions of non-commissioned officers about its utility as a teaching tool.

Method

Subjects and materials. The test required the use of two BFVs. Sixteen military personnel from Fort Benning acted as subjects. All were serving in BFV squads or platoons and all had considerable experience with the thermal sight. Ranks ranged from E4 to E6.

Procedure. In one of the BFVs, the subjects were asked to set up the thermal sight in their own way. This was preparatory to testing some control modifications, and therefore it was hoped they would not realize set-up was also part of the test. In the other BFV, subjects were asked to adopt the role of SMEs to allow themselves to be stepped through the new procedure and then to provide criticism of it. Half the subjects went to one vehicle first and half to the other. In both vehicles, research staff occupied the commander's station and were able to observe the effects of control manipulation on the thermal image through the commander's sight extension. To save time, the thermal sights were turned on and cooled, and the turret was adjusted so that when a thermal image was achieved it would be on a clearly recognizable object.

The observer in the vehicle where subjects could set up the sight in their own way, rated on five-point scales both the quality of thermal image obtained and the degree of competence with which it was obtained. This latter measure was taken to check that there was a homogeneity of ability among the subjects.

The observer in the vehicle in which the subjects were stepped through the procedure also rated the quality of thermal image obtained and recorded whether any errors or failings occurred in executing the procedure. Subsequent to stepping the subjects through the procedure, the observer also recorded their opinions and comments.

Results

Competence of the subject in obtaining a thermal image was rated on a 5-point scale where 5 was expert, 4 was competent, and from there it ranged down to 1, which meant incompetent. When allowed to obtain a thermal image in their own way, 11 of the 16 subjects were rated as expert, and the other 5 as competent. On the quality of thermal image obtained, again rating was on a 5-point scale where 5 meant excellent, 4 meant good, and 1 meant very poor. No subject scored below 4 in either vehicle. In the vehicle where the procedure was tested, all subjects achieved excellent thermal images. In the vehicle where they could use their own method, 13 achieved excellent images and 3 achieved good images. From these results, it is concluded that the subjects were all competent to judge the procedure and that use of the procedure yielded as good a quality of image as did the methods the subjects naturally used.

When the first two subjects were stepped through the procedure, it was realized that confusion could occur between instructions relating to the focus knob and those concerned with the focus barrel (diopter focus). The former is the control for adjusting the focus of the thermal image; the latter adjusts the sight to compensate for differences in eyesight. The wording was amended and the remaining 14 subjects were stepped through using the amended version. All 14 were able to follow the instructions completely and achieved an excellent quality of thermal image. Objectively, therefore, it can be stated that the procedure works.

When the procedure had been stepped through, subjective opinions were sought. Subjects were asked to assess how well they thought the procedure had worked. Three descriptors were offered: worked well, worked fairly well, and did not work well. Ten of the 16 described it as working well; 5 said it worked fairly well; and 1 said it had not worked well at all. Interestingly, this individual had stepped through the procedure without an error and obtained an excellent image. He, along with the other 15 subjects, was next asked whether they felt they could give on the job training using this procedure. All 16 said they thought that they could. Finally, the subjects were asked whether they felt there was a need for such a procedure. Thirteen replied that there was, and 3 said that there was not.

Discussion

The need for the procedure had been clearly demonstrated in the camouflage experiment reported earlier. This experiment demonstrated that the procedure works and gives a good thermal image. Subjects were unanimous in their opinion that they could provide on-the-job training using it. The one criticism voiced was that it seemed to some rather slow, but this may have been because they were being stepped through it. In general, it was judged to work well, and the majority felt that it was needed. The procedure is found in the student handbook by Rollier, Champion, Roberson, and Graber (1987).

Test of Procedure for Marking the Thermal Controls

The procedure for marking the settings of the thermal controls is a logical extension of the procedure for obtaining an initial thermal image. This marking procedure is given in full in the handbook (Rollier, Champion, Roberson et al., 1988). In essence, it requires a gunner to mark the settings of the contrast, brightness, and focus controls once he has obtained a satisfactory initial thermal image. The markings then enable him to pre-set these controls on subsequent occasions or to rapidly re-set them if they are inadvertently displaced. The effectiveness of the marking procedure was tested over a five-day period on a BFV. On returning to the vehicle at the end of the five days, the setting of the controls to the markings was found to yield an immediate usable thermal image that only required sharpening. The marking procedure was reported on in a briefing given at the master gunner's course. Without the knowledge of the experimenters, some among the audience then tested the procedure unofficially, using simple chalk markings on the controls. They subsequently reported that it worked extremely well. The procedure was then formally reviewed by SMEs (instructors from the BFV master gunner's course); the feedback from this review was very favorable.

The marking procedure is very simple. The only proviso is that the controls would need re-marking after ISU maintenance. Marking should therefore be done using a non-permanent medium such as typewriter correction fluid. Further testing is not thought to be necessary.

OTHER RESEARCH

Apart from research aimed at gathering information for thermal training purposes, four other thermally related areas were investigated. The first two, which deal with through-the-sight photography and sight classification techniques, are reported in detail next. The other two, which report experimentation into control modifications for the thermal sight and the use of special thermal camouflage materials, are dealt with in separate documents and will be briefly summarized subsequently.

Through-the-Sight Photography

Research into through-the-sight photography ran parallel with other thermal research. Initially, two lines of research were pursued. These were through-the-sight black and white video and through-the-sight color slide photography. In both cases, the aim was to capture on film what the gunner saw through the thermal sight. The video work was curtailed when the Department of the Army sequestered the video equipment for other purposes. Work on developing techniques for taking through-the-sight color slides has continued.

Background

The need for slides of thermal images of targets that could be used for training purposes was identified early in the thermal research program. The development of the necessary techniques has been an ongoing process that began under the previous contract. The color slides taken in the last major field experiment were very satisfactory and are suited for teaching purposes. A selection of these slides comprises the slide presentation that is part of the thermal training package described above. In view of this success, the technique used is reported in detail below.

Equipment

The camera used to produce the slides was a Nikon F3, 35-mm single-lens reflex camera body with a Nikor f 2.4, 55-mm/MACRO lens. The camera was loaded with 200 ASA (200 ISO) Ektachrome color slide film. The camera was installed in the BFV so that the lens fitted to the commander's eyepiece. The camera was mounted to the sight using a two-pronged bracket (Figure 1). The two prongs of the bracket fitted to the brow-pad mount holes above the sight, and the camera was attached to the bracket by a bolt that fitted in the base of the camera body. This meant that the camera hung suspended in an inverted position from the bracket, with the lens facing the commander's eyepiece. The bracket was adjustable in three dimensions so that the camera lens could be exactly centered on the sight. The camera was activated by a cable release to reduce the chance of camera shake when making long exposures.

Personnel

Two persons were required to take the slides. One operated the thermal sight and occupied the gunner's position, and one operated the camera (the photographer). We found it advisable to obtain the services of a professional photographer for the camera work.

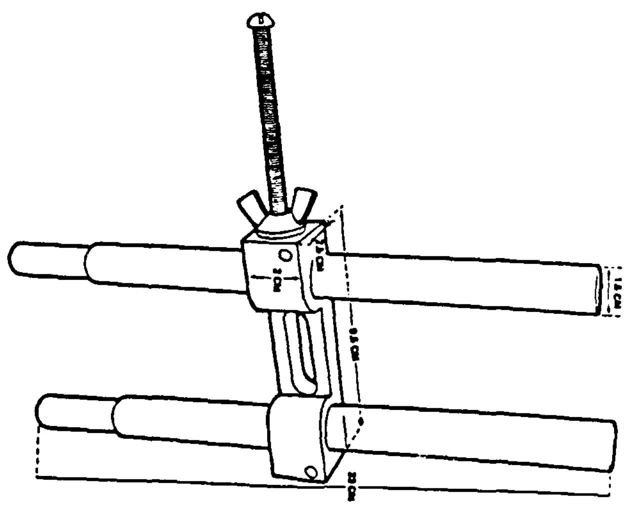

Figure 1. Two-pronged Mounting Bracket

Set-up of Equipment

The equipment was set up in the following manner:

1. The gunner adjusted the focus barrel to obtain a clear daylight image on his own sight, and the photographer adjusted the focus barrel on the commander's sight so that it was set for 20/20 vision (i.e., with a zero correction setting).

2. The gunner obtained a clear thermal image through the sight.

3. The bracket was fitted to the brow-pad mount holes and the camera attached and adjusted until the image of the thermal sight rectangle was centered in the viewfinder of the camera. The camera lens was then focused so that the thermal image was sharp in the viewfinder.

4. A light-proof seal was made between the sight and the camera lens using black electrician's tape.

Photography

To make the image in the camera viewfinder appear as it had in the gunner's sight, the gunner had to increase the brightness of the thermal image to a level that was well above that which gunners normally use and increase the contrast to close to maximum. To obtain the correct degree of offset for contrast and brightness, the gunner had to leave his seat and check whether the image in the viewfinder of the camera was comparable with that shown in his sight.

Photographs were taken with the vehicle engine off (to reduce camera vibration) and with the gun reticle off. Once the camera had been set up, all adjustments of focus for targets at different ranges were made using the focus knob of the thermal sight. The only control settings that were varied on the camera were shutter speed and aperture size. Once photography had begun, the gunner had to take direction from the photographer because only the photographer could see the image in the camera viewfinder. The photographer requested changes in focus, brightness, and contrast, and said when the adjustments were sufficient.

Best results were obtained with the aperture and shutter speed set at f4 and 0.5 seconds respectively. However, it was found to be advisable to bracket these settings and subsequently select the best slide. Therefore, for each target nine exposures were made; that is, with the aperture set at f2.8, f4, and 5.6 and with the shutter speed set at 0.25, 0.5, and 1 second for each aperture setting. This allowed for any variations in brightness of targets and background.

A precise record was kept of both the target and the camera settings for each exposure made. These records enabled the subsequent identification of slides.

Discussion

The methodology described above gives a close approximation to the actual thermal image seen by the gunner; however, it is not exact. The relatively slow shutter speeds appear to give slides showing stationary targets a higher degree of definition than gunners are usually able to see, but conversely a moving target becomes more blurred. Unless care is taken to center the thermal image precisely in the camera's viewfinder, the slide will show a distorted image, especially toward the edges.

Thermal Sight Classification Techniques

Purpose

The purpose of this research was to explore methodologies by which gunners can determine the quality of the thermal image they have obtained, and recognize the need for sight maintenance. Two methodologies were explored. The first was a subjective approach, in which criteria for judging the quality of the thermal image were established and tested. The second was an objective approach that would yield precise data on sight sensitivity to thermal contrasts and precision of focus. These are discussed separately below.

Subjective Criteria

During thermal experimentation in 1985 and early 1986, researchers noted that sights varied considerably from BFV to BFV in terms of the quality of thermal image that could be obtained. In some cases, sight images were so degraded that they would have compromised the combat capability of the vehicle. The quality of image depends on several factors, including the precise setting of the distance between the Infrared Imager and the DEWAR/DETECTOR, the degree and evenness of sight cooling, and whether all the raster lines on the thermal display are working. These mechanical problems manifest themselves as poor focus, fuzziness in parts of the display, and black lines across the display. Because of the number of variables involved and their interactions, it was difficult to categorize the usability of sights. Therefore, a list of subjective criteria was developed for defining sight usability. These criteria were used in the 2 - 7 November 1986 experimentation reported earlier, and were as follows:

Class 1 sights: (a) a clear image is obtainable at ranges exceeding 3000 meters; (b) some targets can be detected and identified in the open at 3000 meters; and (c) all controls function correctly.

Class 2 sights: (a) images reasonably clear out to 3000 meters, although some cloudiness and off-center raster lines are allowed; (b) targets can be detected at ranges in excess of 3000 meters; but (c) targets in the open are unlikely to be identified at ranges in excess of 2000 meters.

Class 3 sights: (a) a clear thermal image is only available in certain parts of LED display; (b) some difficulties are experienced with adjusting focus, contrast, and brightness; (c) thermal signatures at 3000 meters, but (d) identification is unlikely at ranges in excess of 1000 meters.

Class 4 sights: sight is worse than class 3, and therefore basically unusable.

The criteria adopted were linked to the usability of the sight for detecting targets down range, but included some observable failings within the sight image itself. Testing of this classification system showed two weaknesses. The first was that while it enabled a gross differentiation between sights, it was not sensitive to fine nuances. Second, it required SMEs of considerable experience to make the judgments, and even then disparities in judgments occurred because the SMEs tended to treat the first sight they examined as a touchstone and judge the rest relative to that. Thus, if the first sight seen by an SME was good, and met the criteria, it would receive a class 1 rating, but for another SME, who had seen a better sight first, it might be rated as a class 2. This system was clearly too subjective, relied too heavily on experience, and lacked sufficient discrimination.

The complexity of judging sight quality is not to be underestimated. This is illustrated by the brief summary, given below, of the observations of the 2 SMEs who tested the classification system on 7 test vehicles over 5 days (2nd - 7th November 1986).

The thermal sight on test vehicle 1 (TV1), which had been rated as class 1, was rated a 2 on day three because the display had some fuzziness and appeared to be weaker. It returned to class 1 quality, for no known reason, on day six. The thermal sight on TV2 had a weak raster line in the bottom third of display on day three; this posed no usage problem. The thermal sight on TV3 failed on day four at approximately 2235 hours, soon after thermal experimentation had been completed. It was repaired prior to the start of the experiment on day five and was then rated a 2; on day six, however, this sight was given a rating of 1. As with TV1, the observers cannot account for the improvement. The thermal sight on TV4 displayed a <u>foggy area</u> on day four. This cloudiness appeared in the center of the thermal sight display but did not disrupt sight use. The sight on TV5 exhibited <u>jumpiness</u> in the display on day four and was rated a 3; it returned to a rating of 2 on day six for no known reason. The sight on TV6 had two dead raster lines at the bottom of the display on day three and another dead raster line on day four. Contrast and brightness became weak in the center of the display on day six, but none of these factors affected use of the sight during test. The sight on TV7 had a dead raster line in the bottom third of the display, which had no effect on its utility.

In passing, and to maintain a sense of proportion, it should be noted that the thermal sights described above had all been through maintenance and had been upgraded immediately prior to the test, so that they gave better thermal images than the researchers had experienced in earlier experimentation. The researchers looked for patterns in fluctuations in sight quality across all the sights. If this could be shown, then outside factors such as changes in humidity might explain them. No patterns were found. As has been noted, one of the difficulties with a descriptive classification system is the subjectivity of the judgments; another is that it fails to address criticality of fault. Three dead raster lines on the bottom of a display may leave the sight completely usable from a tactical viewpoint; three dead raster lines in the center of the display would have a most adverse effect on gunnery, because the reticle could not be centered on the target.

It was concluded that while the subjective classification criteria had a value for monitoring sight quality in an experimental setting, they were not a suitable tool for BFV gunners or commanders. Primarily, this is because gunners may not always have experience of a sufficient number of sights in different conditions, and may have differing amounts of experience, so that interpretation of the criteria may be expected to differ from gunner to gunner.

Objective Approach

Concept. Concurrent with the development of subjective criteria, a second methodology was hypothesized for testing and classifying the quality of thermal sight images. The concept was as follows. If a board could be developed with heated symbols on it that could be set to a known temperature, and if the temperature contrast ratio between the symbols and the board could also be known, and adjusted, then the ability of a thermal sight to detect differences in temperature could be tested by looking through the sight at the board. In addition, if the symbols could be graded in size, then the precision of focus of the sight could be graded according to the gunner's ability to read decreasing sizes of symbols through the thermal sight. Essentially, the idea was to develop a thermal sight testing device that is analogous to an eye chart: it would test precision of focus, and thermal discrimination. It was further speculated that, by noting the degree of clarity with which different geometric shapes (circles, crosses, squares, and bars) or parts of geometric shapes could be seen, a prediction could be made on the part of the sight that needed the attention of maintenance personnel.

Exploratory research. Two prototype boards were prepared. The first was made from plywood with a heated surface placed over it. Geometric shapes were cut in the heated cover, exposing the wood below; this meant that the symbols would be cooler than the background. The second board was heated, but covered with a heat-reflecting material that contained metal foil. The geometric shapes were cut in the foil so that the heated board would show through, making these areas appear hotter than the board itself when viewed through the thermal sight. The geometric patterns used had a 7:1 height to stroke width ratio. (This ratio was suggested by Night Vision Laboratory, which has also done some pilot work in this area.) The heated boards were designed to be viewed at 100 meters, and the symbols were of three sizes, scaled to equate to a 2-meter high target viewed at 1000, 2000, and 3000 meters.

The boards were tested during the two set-up days for the thermal experimentation conducted in November 1986, and reported earlier. Initial testing showed that a great deal of technical developmental work would be required to obtain an even distribution of heat over the boards, and to control the temperatures of the board relative to the temperatures of the symbols. Adjustments were made in the field, and with each adjustment the researchers gained some confidence in the validity of the concept. The symbols were detectable, became increasingly legible as better heat adjustments were achieved, and there was a suggestion in the findings that different types of symbols did reveal different weaknesses in the thermal sight. For example, it was noted that when circles were viewed, any slight degrees of waviness in the sight picture became much more noticeable than it was when horizontal or vertical lines were viewed.

This research was not pursued any further after the initial experimentation, because it was realized that it would absorb resources that had already been committed elsewhere. The findings regarding the practicality of the concept are, therefore, inconclusive. The research is reported here because it is recognized that if such a device could be produced, and set up in a motor pool, an objective measure of the quality of thermal image could be rapidly and regularly obtained. This would enable BFVs requiring sight maintenance to be more easily identified and would, therefore, materially contribute to the overall combat readiness of a unit.

Modifications to Thermal Sight Controls

During experimentation, it had been noted that gunners often had difficulty in obtaining and maintaining a usable thermal image. At least in part, these difficulties result from poor ergonomic design of the sight controls. For example, the focus knob will rotate about 12 full 360 degree rotations between stops; focus occurs during one part of one of those rotations, usually the fifth. As a result, when rotating this control, gunners can easily miss the focus area and turn on to the far stop before they realize their error. Similarly, the contrast and brightness knobs rotate very freely on their axes. Therefore they are easy for a gunner to displace inadvertently from their settings when he reaches for other controls. Where such problems arise, there are two possible solutions. The first is to provide a training/procedural solution. This solution was adopted to help gunners obtain an initial thermal image, as has been noted previously in this report.

At other times, the solution lies in modifying the controls themselves. Clearly, because many BFVs have already been fielded, this option is only viable if the modifications can be quickly and easily made, at minimal cost, and using minimally skilled personnel. Such a modification has been developed for the contrast and brightness knobs. It comprises the insertion of a vinyl grommet between the panel and the knob. The grommet provides a friction brake on the free rotation of the knobs so that they are stiffer to turn and therefore less prone to accidental movement.

At the same time, a guard was placed on the night sight power on/off switch. This switch is normally unguarded and is subject to accidental switching when gunners make vertical hand movements to reach for other controls. These modifications were tested and adjudged to work well. They are reported in detail in Champion, Rollier, Knapp, and Lewis (1988).

Use of Special Camouflage Materials

Concurrent with the investigation into the effects of camouflage on the thermal detection of targets, the question arose of how friendly vehicles and positions might be hidden from enemy thermal sensors. One suggestion that was explored in detail was the use of the sort of material from which thermal blankets are made. This material contains a metal foil that reflects heat, is lightweight and occupies little space when packed. Experimentation with such material has been continuous and has addressed not merely the effectiveness of the material as a shield to prevent thermal radiations reaching enemy sensors, but also issues of durability and flammability. Insofar as the current camouflage nets provide very little protection from thermal detection, the concept is worthy of exploration. Much of the initial groundwork has now been done, but further research is required before definitive recommendations can be made.

SUMMARY

Thermal research in the 1985-1987 period has been very successful. The exploratory work into the effects of camouflage, cover, and concealment has yielded new and reassuring information about the capabilities of the thermal sight. Using it, some gunners could detect and classify partly camouflaged targets at ranges in excess of 3000 meters. Moreover, the finding that targets that had been camouflaged sufficiently to avoid detection through the daylight sight could still be detected with the thermal sight emphasizes its utility for both day and night operations.

Concurrently, the research yielded guidelines for camouflaging vehicles to avoid detection and, more important, for impeding classification by hostile forces equipped with thermal sensors.

The techniques for through-the-sight photography have been advanced to a point where color slides showing thermal targets are of high quality and can be used for teaching purposes. A subset of those taken has been included in the thermal training package. These slides should prove to be valuable training aids to instructors. They will enable the advantages of particular search and detection techniques to be demonstrated easily, as well as provide a method for teaching students the thermal cues that aid target classification.

The consolidation of the existing guidelines on sight control manipulation, scanning techniques, and range estimation, into a single, reproducible handbook, and the restructuring of the guidelines into step-by-step procedures, should greatly facilitate on-the-job training. The experimental demonstration of the advantages of systematic scanning with polarity set to white hot is also noteworthy.

RECOMMENDATIONS

There is a need for continued research into the use of the thermal sight. The following areas warrant investigation:

1. The identification of the thermal characteristics of threat vehicles, and the development of a simple classification and identification system for them.

2. The capabilities of the thermal sight in conditions of limited visibility.

3. The production of a series of short thermal training films dealing with such topics as Target Detection and Classification (Hostile Forces), Thermal Camouflage, and Thermal Operations in Conditions of Limited Visibility.

In addition, further research is needed in the following areas:

1. Range estimation using the thermal sight.

2. Methods of measuring the quality of thermal image obtained on a sight.

3. Simple and inexpensive modifications to the ISU's controls that will make sight control manipulation easier.

4. Integration of synthetic materials with camouflage nets to provide visual and thermal protection.

5. The preparation of a set of guidelines that will instruct a BFV commander in methods of reducing the probability that his vehicle will be detected and/or correctly classified by threat forces using thermal sensors.

REFERENCES

BIFV range card. (1986). (Unpublished Army Research Institute Material).

BIFV scanning techniques. (1986). (Unpublished Army Research Institute Material).

BIFV thermal operations. (1986). (Unpublished Army Research Institute Material).

Champion, D. F., Rollier, R. L., Knapp, S. D., & Lewis, D. L. (1988). Modification of selected integrated sight unit (ISU) controls. (ARI Research Report 1519). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Rollier, R. L., Champion, D. F., Roberson, P. R., & Graber, J. G. (1988). Procedures and guidelines for thermal imaging. (ARI Research Product 88-39). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Rollier, R. L., Salter, J. A., Graber, J. G., Roberson, P. R., Harbin, K. W., Wilkinson, C. S., Morey, J. C., & Salter, M. S. (1988). Bradley Fighting Vehicle system combat effectiveness: Evaluations of developments in tactics, training, and equipment. (ARI Research Note 88-116). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

APPENDIX A. TABLE 7.

Targets Used in Scenario A

Target Number	Target	O-T Range in Meters[a]	Vehicle Attitude[b]	C3 Condition(s)[c]
1	M113	630	Right flank	In partial defilade with cut vegetation over vehicle
2	HMMWV	630	Left flank	Cut vegetation providing partial coverage
3	M578 (VTR)	630	Right flank	Shallow in tree line with cut vegetation over exhaust
4	M60	1450	Left oblique (Facing away)	Cut vegetation covering exposed section of vehicle
5	M577	1850	Right flank	Shallow in tree line
6	Truck (2.5-ton)	2070	Right flank	Behind large oak tree
7	M901 (ITV)	1865	Right flank	Road wheels in defilade
8	Fuel Truck (5-ton)	2400	Right flank	In open
9	M1	3150	Right flank	Behind two large pines with cut vegetation covering entire vehicle
10	M113	3050	Right flank	Cut vegetation providing partial coverage
Extra[d]	M2	1865	Left flank	Special thermal material providing complete coverage

Note. All vehicle engines were idling. [a] O-T Range: The range from the observation line to each target. [b] Attitude: As seen from the observation line on Bush Hill. [c] C3: Camouflage, cover, and concealment. [d] The extra target vehicle was an M2 Bradley that had been placed behind a prototype thermal camouflage material.

APPENDIX A. TABLE 8.

Targets Used in Scenario B

Target Number	Target	O-T Range in Meters[a]	Vehicle Attitude[b]	C3 Condition(s)[c]
1	HMMWV	630	Left flank	In partial defilade with cut vegetation on front
2	M113	630	Right flank	Shallow in tree line with cut vegetation over exhaust
3	M578[d] (VTR)	805	Right flank	Shallow in tree line with cut vegetation over exhaust
4	M901 (ITV)	1300	Left oblique (Facing away)	Shallow in tree line
5	Truck (2.5-ton)	2100	Right flank	Behind single pine tree
6	M113	1850	Right flank	Road wheels in defilade with vehicle behind scrub oak
7	M60	1850	Left flank	Cut vegetation covering entire vehicle
8	Fuel Truck (5-ton)	2400	Right flank	In open
9	M1	3150	Right flank	Behind two large pines with cut vegetation covering entire vehicle
10	M557	3050	Right flank	Cut vegetation over exhaust
Extra[e]	M2	1865	Left flank	Special thermal material

Note. All engines were idling. [a] O-T Range: Range from observation line to each target. [b] Attitude: As seen from observation line on Bush Hill. [c] C3: camouflage, cover, and concealment. [d] M2 was substituted for M578 on evening of 7 November because M578 developed mechanical problems. Although M578's engine was shut down, first two subjects in each turret were able to detect it. By the time third set of subjects entered turrets, vehicle had cooled to the point that it presented no thermal signature. [e] Extra target vehicle was BFV that had been placed down range for other test.

APPENDIX B. TABLE 9.

Temperature (F) and Humidity (Percent) Recorded on the Four Days of Experimentation

Date	Time (hours)	Temperature (degrees F)	Humidity (Percent)
4 November	6 p.m.	65	87
	10 p.m.	63	93
5 November	6 p.m.	73	79
	10 p.m.	67	90
6 November	5 p.m.	77	54
	10 p.m.	62	90
7 November	6 p.m.	79	65
	10 p.m.	71	84

Note. Weather data obtained from Detachment 10, 5th Weather Squadron, Lawson Army Air Field, Fort Benning, Georgia.

The humidity readings given in Table 9 are probably higher than was experienced. This was because the weather station that supplied the data is located 350 feet lower than Bush Hill and considerably closer to the Chattahoochee River. In that relative humidity may be expected to have risen as the temperature fell, and insofar as increases in humidity reduce to some extent the amount of radiated heat from a target that reaches a thermal sensor, it is theoretically possible that there was some degradation in the quality of thermal images as the evening progressed.

APPENDIX C. FACTORS AFFECTING THE EXPERIMENTAL DESIGN

Difficulties in Implementing the Experimental Design

The experiment was designed with the following objectives in mind. First, that in each scenario the 10 targets would be well separated from each other, so that each target detection would be independent. Second, that the 10 target locations in scenario A would be different from the 10 target locations in scenario B. Operationally, these requirements could not be met. The test areas available at Fort Benning that had sufficient range to permit targets to be placed out to 3000 meters were narrower than was desired, more heavily wooded, and contained areas of dead ground because of hills and folds in the terrain. Of those available, Bush Hill had the lowest number of disadvantages; however, it was far from ideal. It proved impossible to place 10 targets in such a manner as to guarantee multiple detections could not occur. Equally, it proved impossible to identify 20 separate target locations.

Multiple detections. The extent to which multiple detections occurred for each test subject was impossible to assess. The SMEs who occupied the commanders' positions in the BFVs and monitored what the subjects saw through the commander's sight extension reported that, on occasions, up to three targets were visible concurrently through the sights. However, the test subjects did not always notice and/or report all of them. Moreover, because subjects reported target detections in a serial manner, there was no way of subsequently knowing whether the gunner who reported two or three of the targets had noticed them concurrently, or only noticed the second after reporting the first. Clearly, there is a high probability that multiple detections occurred for some gunners on some occasions. However, because the possibility of multiple detections existed equally for all subjects in both groups, it does not bias the data. For analysis purposes, the detections are of necessity treated as though they were independent.

Control of informational interchange between test subjects. The intent of the experimental design was that each subject's performance would be independent: that is, uninfluenced by the performance of others. In scenario A, this was achieved. The control group, who arrived on the first day of experimentation, had no contact with the treatment group, who arrived on the second day. Within each group, those waiting to enter a turret were separated from those who had already taken part in the experiment. For scenario B, the same degree of control could not be maintained. For each group, 48 hours elapsed between the end of scenario A and the start of scenario B. During this period, the subjects were out of the jurisdiction of the experimenters. It was therefore impossible to ensure that no discussion took place. Indeed, there is evidence that discussion did take place within groups and that the possibility of discussion between groups must be acknowledged. In scenario A, 5 of the 18 subjects in the control group scanned for targets with the polarity consistently switched to black hot. In scenario B, only one subject scanned consistently with this setting. As will be shown subsequently, in this experiment scanning with polarity set to white hot yielded a greater number of detections. It is therefore hypothesized that in discussing their relative performances, the gunners in this group realized that those who scanned in white hot had found more targets and some decided to use this method in scenario B. Similarly, in scenario B, some gunners seem to have expected 10 targets. This may have been a deduction drawn from knowledge of best performances during scenario A and may have caused subjects to persist until 10 targets were found during scenario B.

Other operational considerations. During scenario B, one of the target vehicles broke down while being driven to its target location and an alternative vehicle was therefore placed at that location. Regrettably, the vehicle that had broken down could not be removed from the test area prior to the start of experimentation. As a result, for the treatment group, scenario B contained 11 potential targets rather than 10. Observers were instructed to tell subjects to disregard the broken-down vehicle if they detected it. The presence of this additional vehicle did not in itself substantially disturb the integrity of the experimental design.

APPENDIX D. TABLE 10.

Results of Multiple Regression Analysis: Detections On Polarity Usage and Scanning Pattern for the 35 Subjects in Scenario A

Regression of Detections on Scan Pattern.

	SS	df	MS	F	p
Regression	31.082	1	31.082	14.545	<.001
Residual	70.518	33	2.137		
Total	101.6	34			

Coefficient of Determination .306

Regression of Detections on Polarity.

	SS	df	MS	F	p
Regression	27.82	1	27.82	12.433	<.005
Residual	73.78	33	2.236		
Total	101.6	34			

Coefficient of Determination .274

Multiple Regression. Detections on Polarity and Scanning Pattern.

	SS	df	MS	F	p
Regression	44.70	2	22.351	12.57	<.005
Residual	56.90	32	1.778		
Total	101.6	34			

Coefficient of Determination 44

Partial F tests.

	SS	df
(1) Full Reg. Residual	56.90	32
(2) Reg. on Scan Pattern Residual	70.52	33
(3) Reg. on Polarity Residual	73.78	33

	SS	df	MS	F	p
(2)-(1)	13.62	1	13.62	7.66	<.01
(3)-(1)	16.88	1	16.62	9.49	<.005

Note. Polarity usage and choice of scanning pattern both contribute significantly to improving detection rates. These two factors explain 44 percent of the variance in detection rates among the subjects.

APPENDIX E. TABLE 11.

Results of Multiple Regression Analysis: Scanning Times on Polarity Usage and Scanning Pattern for the 35 Subjects in Scenario A

Regression of Scanning Times on Scan Pattern.

	SS	df	MS	F	p
Regression	631550	1	631550	3.3275	NS
Residual	6263218	33	189794		
Total	6894768	34			

Coefficient of Determination .09

Regression of Scanning Times on Polarity.

	SS	df	MS	F	p
Regression	1937998	1	1937998	12.902	<.005
Residual	4956770	33	150205		
Total	6894768	34			

Coefficient of Determination .28

Multiple Regression. Scanning Times on Polarity and Scanning Pattern.

	SS	df	MS	F	p
Regression	2075258	2	1037629	6.890	<.005
Residual	4819510	32	150610		
Total	6894768	34			

Coefficient of Determination .30

Partial F Tests.

	SS	df
(1) Full Reg. Residual	4819510	32
(2) Reg. on Scan Pattern Residual	6263218	33
(3) Reg. on Polarity Residual	4956770	33

	SS	df	MS	f	p
(2)-(1)	1443708	1	1443708	9.586	<.005
(3)-(1)	137260	1	137260	0.911	NS

Note. Polarity usage significantly affects scanning time. Once polarity usage had been taken into account, the choice of scanning patterns did not contribute significantly in explaining scanning time. Polarity usage alone explained 28 percent of the variance in scanning times.